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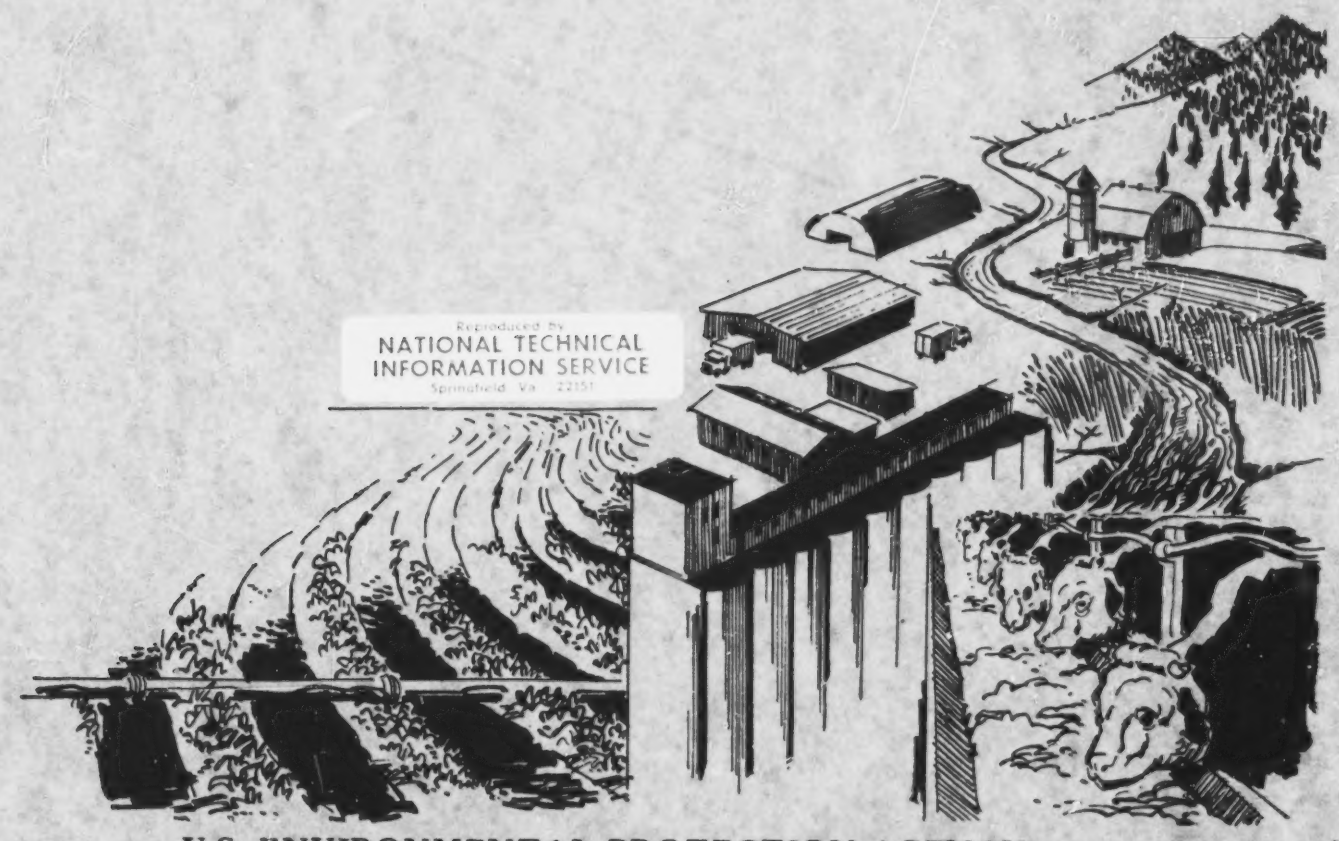

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SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

1. Report No. | 2. | 3. Accession No. W 72-08298

4. Title
ROLE OF ANIMAL WASTES IN AGRICULTURAL LAND RUNOFF

5. Report Date

6.

8. Performing Organization Report No.

7. Author(s)
~~Robbins, J.W.D., Howels, D.H., and Kriz, G. J.~~

10. Project No. EPA Program 13020 DGX 08/71

9. Organization
Department of Biological and Agricultural Engineering, ~~School of Agricultural and Life Sciences~~
North Carolina State University, Raleigh

11. Contract/Grant No.
~~EPA/ORM Grant No. 13020 DGX 08/71~~

13. Type of Report and Period Covered

12. Sponsoring Organization Water Pollution Control Research Series

15. Supplementary Notes ~~Role of Animal Wastes in Agricultural Land Runoff, U.S.~~ Environmental Protection Agency, ~~Grant 13020 DGX~~, August 1971, 114 p., 32 fig., 19 tab., 75 ref., 2 append.

16. Abstract

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More than 1500 stream and lagoon effluent samples were collected with an automatic sampler developed for the study. The samples were analyzed for bacteria, nutrients, and degradable organics. Hydrological and waste management data were also collected.

Study results point to the superiority of land spreading for the disposal of animal wastes. Good soil and water conservation practices should be used to minimize the movement of wastes into streams. Higher rates of runoff result in heavier pollution. The location of disposal areas away from streams is important in controlling the amount of entering wastes. Even when land disposal areas are poorly located, the amount of pollution entering streams is usually low; and watershed factors, such as surface culture and ease of erosion, are of primary importance in governing the magnitude of pollution which reaches the streams. Direct dumping of animal wastes, treated or untreated, into streams is completely unacceptable and should be prohibited. (Dorland-~~ISU~~) Iowa State

17a. Descriptors

*Farm wastes, *runoff, *water pollution, *farm lagoons, waste disposal, sampling, analysis, disposal

17b. Identifiers

~~*Animal wastes~~, *agricultural land runoff, ~~agricultural wastes~~

17c. COWRR Field & Group 05B

Copy available from GPO Sup Doc. microfiche
From NTIS as PB 209 213 $0.95

18. Availability
Supt. of Documents, U.S. Gov't. Print. Off. Washington, D.C. 20402

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

Send To:
WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D.C. 20240

Abstractor Steven Dorland | Institution Iowa State University

WRSIC 102 (REV. JUNE 1971) GPO 913-251

ROLE OF ANIMAL WASTES IN AGRICULTURAL LAND RUNOFF

by

Department of Biological and Agricultural Engineering
School of Agriculture and Life Sciences
North Carolina State University at Raleigh

for the

ENVIRONMENTAL PROTECTION AGENCY

Grant 13020 DGX

August, 1971

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price $1.25

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ABSTRACT

Twelve typical agricultural areas representing three types of animal waste management techniques--lagooning, direct discharge into streams and land spreading including pasture and drylot units--were studied to determine the amounts of and factors governing stream pollution from swine, dairy, beef, and poultry production operations.

More than 1500 stream and lagoon effluent samples were collected with an automatic sampler developed for the study. The samples were analyzed for bacteria, nutrients, and degradable organics. Hydrological and waste management data were also collected.

Study results point to the superiority of land spreading for the disposal of animal wastes. Good soil and water conservation practices should be used to minimize the movement of wastes into streams. Higher rates of runoff result in heavier pollution. The location of disposal areas away from streams is important in controlling the amount of entering wastes. Even when land disposal areas are poorly located, the amount of pollution entering streams is usually low; and watershed factors, such as surface culture and ease of erosion, are of primary importance in governing the magnitude of pollution which reaches the streams.

Effluents from swine waste lagoons were found to exceed raw domestic sewage in strength and should not be discharged without further treatment. Direct dumping of animal wastes into streams is completely unacceptable and should be prohibited.

This report was submitted in fulfillment of grant 13020 DGX between the Environmental Protection Agency and North Carolina State University at Raleigh.

Key Words: Animal wastes, farm wastes, runoff, agricultural wastes, water pollution, farm lagoons

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ABBREVIATIONS

Symbol	Name
BOD	biochemical oxygen demand
BOD_5	five-day BOD
COD	chemical oxygen demand
FC	fecal coliform
FS	fecal streptococci
H	number of unit hogs (100 lb live weight)
M	mean
NH_3	ammonia nitrogen
NO_2	nitrite nitrogen
NO_3	nitrate nitrogen
No.	number of values
OP	orthophosphate
q	flow rate
q_t	total flow rate
q_b	base flow rate
q_o	runoff flow rate, $q_t - q_b$
r	correlation coefficient
R^2	coefficient of determination
s	standard deviation
T_x	maximum daily atmospheric temperature
T_n	minimum daily atmospheric temperature
TC	total coliform
TN	total (Kjeldahl) nitrogen
TOC	total organic carbon
TP	total phosphate
TS	total solids
VS	volatile solids

CONCLUSIONS

1. The natural pollution load on streams draining agricultural basins free of farm animals can be appreciable during periods of rainfall and runoff and should be taken into consideration in water quality management.

2. Except for nitrate penetration into the groundwater at one site, pollution indices for land drainage from waste spreading and control watersheds paralleled stream hydrographs with extended drag-out on cessation of surface runoff. The rise in indices with runoff was roughly proportional to increase in flow of stream over base flow. Where nitrate had entered the groundwater, concentrations in stream were inversely proportional to flow, peaking under dry-weather conditions.

3. The extent of water pollution caused by farm animal production units is more dependent on production and waste management practices than on the volume of wastes involved.

4. The land provides a natural treatment system for animal wastes and land spreading is a very effective means to prevent water pollution. Even in cases where the disposal sites are poorly located or managed or where pastured animals have access to streams, the amount of pollutants (natural plus animal wastes) which reach streams is a very small proportion (less than 10 percent) of the potential from the animal wastes deposited in the watersheds. Proper land spreading can reduce pollutants entering streams by more than 99 percent. Criteria for this purpose are provided.

5. Differences in watershed characteristics such as slope, soil permeability, surface culture, drainage pattern, degree of erosion, and other factors are of great significance in determining the quality of streams draining agricultural basins. This emphasizes the importance of good soil and water conservation practices to minimize the movement of wastes into streams.

6. Although estimating equations developed from this study with temperature, number of animals and rate of land runoff as independent variables and pollution parameters as dependent variables do not have general applicability, predictive relationships held quite well for many sets of data collected over short periods of time showing promise that estimating equations to serve the needs of water quality management can be developed with a more detailed and longer term study, particularly if the equations include effects of more hydrological variables.

7. The use of anaerobic lagoons as the sole means for treatment of animal wastes is an unsatisfactory practice in areas where rainfall exceeds evaporation. Even when lagoons provide more capacity

per animal than USDA and other recommended standards recommend, effluents still exceed raw domestic sewage in strength. Although the amount of surface discharge and resulting stream pollution from lagoons can be lessened by reducing the amount of wash-water, diverting runoff from surrounding areas, and locating lagoons to prevent surface and subsurface inflow, at least intermittent surface discharge is assured unless deep seepage is excessive.

8. The practice of dumping fresh animal wastes directly into streams causes severe pollution. Swine and dairy production units are the principal sources in North Carolina. Although the water quality downstream from a discharge point is largely predictable from characterization of fresh wastes, the quality varies erratically with flow rate depending on the amount of solids carried by the water. The large pollution load imposed on a stream by a direct discharge operation overshadows the load from surrounding pastures or other land disposal operations. The streams are generally more polluted in the summer and pollution increases with surface runoff.

9. Simple regression analyses support the conclusion that total organic carbon can be used as a rapid and reliable measurement of pollution from animal wastes and for the estimation of other pollution indices.

10. Antibiotics and toxic metals in animal feeds apparently interfere with the BOD_5 analysis of animal wastes at levels above 60 mg/l, necessitating the concurrent use of TOC (or COD) for the estimation of degradable organics and oxygen demand at BOD_5 levels above 60 mg/l.

11. The state of the art of animal waste management for pollution control is primitive, indeed. Many questions remain with regard to animal waste characterization, related water quality studies, and the proper design of lagoons and other waste treatment facilities used in conjunction with or independent of land spreading.

RECOMMENDATIONS

1. Natural stream pollution should be taken into consideration in water quality management. The extent of pollution caused by farm animals should be distinguished from that coming from other pollution sources that naturally occur in watersheds.

2. In view of the many desirable characteristics of land disposal systems, adequate resources should be expended to improve their components and to promote their widespread use. Pilot systems should be established to resolve operational problems, improve system design, and demonstrate effective management practices.

3. The direct discharge of animal wastes to water courses should be prohibited.

4. The effluent from anaerobic lagoons should receive further treatment or be disposed of by land spreading.

5. The total organic carbon test is recommended as a key index in animal waste studies and surveys and for the estimation of other pollution indices.

6. Additional research should be undertaken to:

   a. provide additional factual data on the various forms and extent of pollution from natural sources,

   b. develop reliable standards for anaerobic and aerobic lagoons with economical secondary treatment units such as effluent irrigation and plant-soil filters for use where circumstances preclude classical land spreading,

   c. develop analytical and stream survey procedures for animal waste,

   d. determine the true extent of groundwater pollution associated with animal wastes giving consideration to the areal distribution of the pollution, and

   e. develop generally applicable estimating equations that include the essential variables for predicting the amount of stream pollution arising from various animal production and waste management units.

7. The following criteria are tentatively recommended for the guidance of land disposal:

a. apply wastes uniformly,

b. govern rate, time, and frequency of application for maximum nutrient utilization by plants,

c. select disposal areas with low erosion potentials,

d. do not apply waste on grassed waterways or other drainage paths,

e. plow waste under on barren fields,

f. locate drylots away from streams and hillsides leading directly to streams,

g. provide at least 100 feet of vegetated area between drylots and streams or drainage paths, and

h. when stocking at a high rate, pasture animals away from streams and drainage paths.

In essence, these factors are met by locating the production areas according to hydrological dictates and by following standard soil and water conservation practices.

INTRODUCTION

General Background

This report presents findings of a study initiated to quantify pollution loads in runoff from farm animal production areas and to evaluate factors governing the timing, volume, and concentration of waste discharges. The overall study is an attempt to determine whether and under what conditions wastes from swine, dairy, beef, and poultry production areas are a significant source of stream pollution and to provide information that will aid in water quality management.

Agriculture is increasingly alleged to exert a detrimental influence on water quality (Wadleigh, 1968). Effluents from farm animal production areas are particularly susceptible to generalizations that mark them as a major contributor to surface water pollution. For example, the potential significance of animal wastes as a pollutant is often viewed in terms of human waste equivalents. The population equivalent is about 16 for cattle, 2 for swine, and 1/7 for poultry (Environmental Pollution Panel, 1956). For the nation as a whole, farm animals produce ten times as much wastes as the human population. In North Carolina the wastes from farm animals are equivalent to wastes from a population of more than 15 million (Howells, 1969). While such generalizations may carry significant implications in water quality management, they are hazardous if taken out of context. The extent to which animal wastes are attenuated before reaching water courses has not been defined by field tests or surveys. Knowledge concerning the actual pollution imposed on streams from point and diffused sources of animal wastes is necessary to properly assess the problem and formulate meaningful waste control, treatment, and disposal requirements for surface water protection.

Eutrophication of lakes, reservoirs, and estuaries has led to speculation as to the importance of effluents from animal production areas as a source of nutrients, in particular nitrogen and phosphorus. Various federal, state, and local authorities have advocated controlling the phosphorus content of waters to a level low enough to prevent algae growth. The threshold value has been reported to be from 10^{-5} mg/l to 10^{-1} mg/l of phosphate (Levin, 1967). There is evidence that water containing phosphorus above the threshold value will sustain increased algae growth with added phosphate. In addition to its stimulation of unwanted aquatic plant growth, nitrogen in its various oxidation states is harmful to the health of aquatic and terrestrial animals when present at sufficient levels. Fish kills occur when water contains high amounts of ammonia (Rainwater and Thatcher, 1960). High nitrate levels in drinking water may cause methemoglobinemia in humans (Bosch et al, 1950). Abortions in cattle and sheep have occurred from ingestion of high nitrate water (Wadleigh, 1968).

Animal wastes are a concentrated source of bacteriological organisms normally used to characterize water quality (Robbins et al, 1969b). The dearth of investigations of relationships between water contamination caused by animal wastes and disease transmission is somewhat of an anomaly. Health problems associated with other means of contact with animal wastes have been of concern to public health agencies for generations. A large number of diseases of microbiological etiology are known to be transmitted through animal wastes. One of the most important is salmonellosis (Decker and Steele, 1966).

Animal wastes can deplete the dissolved oxygen in receiving streams as the wastes undergo decomposition. Henderson (1962) concluded that runoff from animal-growing areas can make municipal loads appear insignificant on an oxygen-demand basis. Oxygen depletion in streams caused by runoff from livestock feeding operations were considered to be the primary cause of 15 of 27 fish kills in Kansas during 1964 (Smith, 1965).

Animal production is an important agricultural enterprise in the Southeast from the standpoint of wastes produced and probable effects on receiving streams. Animal waste management practices can be categorized as land disposal (including pastures), lagooning, and direct discharge to streams.

Objectives of the Investigation

The objectives of the investigation were to determine the extent to which effluents from existing farm animal production operations contribute to stream pollution and to evaluate the factors governing the amount of pollution from these sources. Sub-objectives necessary for the study were: (1) to develop equipment for the survey; (2) to develop plans of sampling, sample handling, and sample analyses; and (3) to determine the appropriate parameters for quantifying the pollution loads.

REVIEW OF LITERATURE

The magnitude of the farm animal waste management problem was pointed out in a report by the Secretary of Agriculture (1969) to the President of the United States in which animal wastes in the United States were stated to exceed wastes from any other segment of our agricultural-industrial-commercial-domestic complex. The report estimated that approximately 1.7 billion tons of animal wastes are produced annually, about one-third of which is liquid. The federal budget for fiscal year 1969 included over $2 million for research and development to minimize pollution from animal wastes. Even larger sums are expected to be available for expenditure each year for the next five years.

Farm Animal Situation

The value of livestock and poultry on the nation's farms and ranches totaled $23.5 billion in January 1970. Meat animals accounted for $22.9 billion. The value of the cattle inventory was $20.2 billion while hogs and pigs were valued at $2.2 billion. The chicken inventory was valued at $581 million and turkeys at $36.8 million (NCDA, 1970). North Carolina receipts from sales of livestock and livestock products in 1968 were estimated at $488 million (NCDA, 1968a).

The number of farms growing animals has tended consistently downward in the nation and in North Carolina (NCDA, 1968a). Animal production is becoming more and more specialized as herds increase in size. There has been a marked shift to confinement housing, coincident with an increase in size of individual operations. Problems of waste management such as stream pollution and economical disposal of wastes have occurred because confinement housing has caused large numbers of animals to be raised on relatively small areas and wastes to be concentrated in feeding areas. Approximately 95 percent of livestock and poultry currently being produced on North Carolina farms is marketed. Fifteen years ago one-third of total production was consumed on farms where produced.

Swine

The swine industry produces about one-tenth of the total cash receipts from farm products in the United States (NCDA, 1970). North Carolina usually ranks twelfth in the nation in hog inventories and tenth in pigs born. Production of hogs at the national level tends to follow cycles over a comparatively short number of years (NCDA, 1968a). Production in the Southeast and in North Carolina is generally consistent with national cycles. Hogs on North Carolina farms have fluctuated between peaks of slightly more than 1.5 million (record high of 1,675,000 in 1916) and valleys of slightly more than one million head (NCDA, 1968b).

The December 1969 estimate of 56.7 million hogs and pigs on the nation's farms was six percent less than the 60.6 million on hand a year earlier. All hogs and pigs on North Carolina farms were inventoried at 1,612,000 head, up six percent from a year earlier (NCDA, 1970).

There were 3,691 farrowing houses, 601 nursery units, 270 sow gestating units, 3,040 feeding floors, and 2,488 manure lagoons in North Carolina during 1968 (Jones, 1968). About 40 percent of the hogs were finished in concrete-floored houses. Regional distribution of swine growing in North Carolina based on the sum of top hogs and feeder pigs produced and sows kept for breeding, was: Coastal Plains - 75 percent; Piedmont - 21 percent; and Mountains - four percent. There were 27,839 producers of hogs for sale, but only 7,000 with more than twelve farrowing sows.

Cattle

Cattle and calves on the nation's farms and ranches were estimated at 112 million as of January 1970. The North Carolina value was just over one million head consisting of 318,000 milk animals and 763,000 beef animals. Milk animals in the Tar Heel State declined two percent from the number of a year earlier. An increase of six percent in beef animals more than offset the decline in milk animals as has been the case for the past decade. North Carolina ranks 35th in all cattle (NCDA, 1970).

Regional distribution of cattle in North Carolina is:

Region	Dairy	Beef
Piedmont	55%	45%
Mountains	30%	26%
Coastal Plains	15%	29%

Poultry

At the beginning of 1970 chickens excluding commercial broilers on the nation's farms were estimated at 432 million, up three percent from a year earlier. Turkeys were estimated at 6.7 million, up one percent. Chickens on North Carolina farms, excluding commercial broilers, totaled 23 million while turkeys totaled 769,000 head (NCDA, 1970). Commercial broiler production in North Carolina was almost 263 million head in 1967. The Tar Heel State ranks fourth in turkeys and chickens. Broilers are second only to tobacco in cash receipts from farm marketings.

The distribution of poultry throughout the state is:

Region	Layers	Broilers	Turkeys
Piedmont	63%	42%	25%
Mountains	10%	25%	5%
Coastal Plains	27%	33%	70%

Turkeys are concentrated in the Southern Piedmont and Southern Coastal Plains. Almost two-thirds of the broilers are from five counties representing the three regions of the state (NCDA, 1968a).

Properties of Animal Wastes

The properties of animal wastes can be classified as physical, chemical, and biological. A great variability in properties is reported in the literature. The variations may reflect different conditions of production, management, climate and other factors. Also, today's conditions and analytical techniques are radically changed from those of a few years ago. Methods of collecting, handling, and analyzing the wastes partially accounts for the wide differences in properties reported. For example, animal wastes may be considered as only excreta (solid and/or liquid) or may include litter or bedding, spilled feeds, cleaning materials, chemicals used for pest control, cleaning water, and waste carcasses. Analytical techniques for characterizing animal wastes were adopted from those used for municipal wastes although animal wastes are considerably more concentrated and of different composition. Thus, analytical techniques have been suggested as a cause for the differences (Taiganides and Hazen, 1966). Other causes for differences in the reported properties of animal waste may be attributed to the physiology (size, sex, breed, age, health, and activity) of the animal, the feed ration (digestibility, protein and fiber content, and additives) and the environment (temperature, humidity, light, antecedent moisture, and time or age) (Robbins and Kriz, 1969).

Animal wastes contain large populations and varieties of bacteria and viruses, some of which may be pathogenic to man and animals. Gieldrich (1966) estimated that the per capita production of the fecal coliform indicator microorganism is:

hog	.....	$8{,}900 \times 10^6$ col/day
cow	.....	$5{,}400 \times 10^6$ col/day
chicken	.....	240×10^6 col/day

Decker and Steele (1966) discussed the health aspects and vector control associated with animal wastes. They indicated that many diseases organisms originating in animal waste are readily waterborne.

Swine

Muehling (1969) concluded that the average BOD_5 production is about 0.32 lbs. per day per hog weighing 100 to 125 lbs. He also reported that the BOD_5 for hog waste is approximately two-thirds the ultimate BOD, the average chemical oxygen demand (COD) for a 100-lb. hog is about 1.4 lbs. per day, and the BOD_5/COD ratio is usually about 0.3 for swine wastes.

Taiganides (1963) concluded that 60 percent to 70 percent of the original amount of the ingredients in the feed eventually appear in the fecal and urine excreta of the hogs. Muehling (1969) reported that the

most generally accepted estimate of the amount of waste from a hog is five percent to eight percent of its live weight per day of which 10 to 15 percent is dry matter. A 100-lb. hog will produce approximately one lb. of dry solids per day. The wet manure per 1000 lbs. live weight hog averages 28,000 lbs. per year; the major fertilizing elements average: nitrogen (N), 175 lbs; phosphorus (P_2O_5), 95 lbs; and potassium (K_2O), 128 lbs. An average fertilizer value of hog manure is 0.7 percent N, 1.4 percent P_2O_5, and 0.4 percent K_2O. There is less urine than solids, but the urine contains about 50 percent of the fertilizer nutrients. Taiganides and Hazen (1966) reported that 1000 gal. of fresh swine manure contains 47 lbs of Ca, 6.6 lbs. of Mg, 12 lbs. of S, 2.3 lbs. of Fe, 0.5 lbs. of Zn, 0.35 lbs. of B, and 0.13 lbs. of Cu.

Cattle

Wadleigh (1968) estimated that 400 cows will produce about 14 tons of solid wastes and 4.5 tons of liquid wastes daily. Cattle wastes were characterized by Witzel et al (1966). In addition to analyses of the raw wastes, studies were made to evaluate the settleable properties of the diluted wastes. Daily production values in pounds per 1000 lb. live animal weight were:

	BOD_5	COD	TS	N
Dairy Bull	0.76	4.19	4.21	.24
Dairy Cow	1.32	5.78	6.80	.37
Beef	1.02	3.26	3.26	.26

Physical properties of dairy animal wastes were described by Sobel (1966) in terms of bulk density, partial size distribution, moisture content, and solids composition.

Hemingway (1961) reported that 10 tons of cattle manure contains: 350 lbs. ammonia sulphate, 120 lbs. superphosphate, 100 lbs. muriate of potash, 68 lbs. anhydrous Mg sulphate, 182 ppm Mn, 23.5 ppm B, 19.8 ppm Cu, 1.7 ppm Co, and 2.3 ppm Mo. Herron and Erhart (1965) found that manure from feedlots has 78 percent dry matter with 31 lbs. N, 9 lbs. P, and 16 lbs. K per ton. They concluded that the classical plant nutrient analysis of 10-5-10 for cattle manures is not representative of manure from western feedlots.

Poultry

Wadleigh (1968) estimated that one hundred thousand fowls produce five tons of wastes per day. McHenry (1961) found that the weight of manure voided by laying hens is approximately twice that of the feed consumed. The weight at zero moisture content is about 1/2 the weight of feed consumed. One thousand broilers produce 2.25 tons of dry droppings during a ten-week growing period. One hundred turkeys produce two tons during a 26-week growing period. Tower and Barr (1965) found that the volume of manure from 1000 hens is 20 tons/yr.

Hartman (1965) found that poultry manure dried to 12 percent moisture contains 3.5 to 4 percent N. Phelps (1965) reported that fresh poultry manure contains 1.8 percent N, 1.4 percent P, and 0.6 percent K. Manure that is several years old contains 2.2 percent N, 1.1 percent P, and 1.0 percent K. Other elements found in the manure include 2.2 percent CaO_2 and some zinc.

Toth (1965) performed laboratory and field tests on dried poultry excreta and bedding (bagasse). His results indicated that one ton was equivalent to 1200 lbs. of 5-10-10 fertilizer in terms of crop response.

Related Studies

Ludwig et al (1961) reported on urban and rural pollution in Imperial Valley waters. Their data indicated that agricultural lands, with and without farm animals, contribute significant amounts of bacterial and BOD loading to surface waters. Henderson (1962) pointed to the apparent neglect of the fate of animal excrement after deposition on land surfaces with respect to their contribution to organic pollution and bacteriological contamination of surface waters. He cited limited data concerning the actual BOD contribution of agricultural land drainage to a stream. His data showed a correlation between rate of flow and BOD_5. The lowest BOD_5 (0.6 ppm) was under drought condition when the flow was 0.1 cfs per square mile. At a flow rate of 1.5 cfs per square mile, the BOD_5 reached its maximum observed value (3.6 ppm) within the test series and maintained this value at the maximum observed flow rate of 13 cfs per square mile.

Fish (1964) reviewed considerations for pollution prevention of surface waters by animal wastes. To explain why this potential pollution source has not appeared sooner as a major problem, he mentioned that farm units are still very widespread and are often remote from rivers and streams of consequence. He also cited four reasons why farm effluent disposal could not be dealt with on the same basis as sewage and trade effluent disposal: (1) farm effluents vary with time and between similar farms; (2) operations on farms are quite alien to effluent purification processes; (3) farm effluents generally cannot be purified to a high standard of purity in conventional sewage plants; and (4) available public sewage works are often incapable of handling much farm effluent.

Webster and Clayton (1966) concluded that organic pollution of streams from farm animal wastes in terms of problems, processes, and control methodologies has been neglected by water pollution, health, and agricultural agencies.

Meiman and Kinkle (1966) studied the effect of impacted land use (grazing and irrigation) on surface water quality. Bacteria indicators gave a better indication of land use impact than did suspended sediment or turbidity. All indicator organisms gave convincing evidence of pollution on the grazed and irrigated watershed over and above that occurring on a control watershed. Of the three indicator bacteria groups used--fecal coliform (FC), total coliform (TC), and fecal streptococci

(FS)--FC and TC were the most sensitive in detecting the grazing and irrigation impact with FC being the best. The preliminary study indicated that bacteria concentrations in the stream were related to overland flow, stream discharge, and season of the year. Storm characteristics were very important in raising natural levels of organisms and in magnifying organism differences in the natural versus impacted stream. Ratios of FC/FS ranged from less than 1 to 4.5 on natural areas and less than 1 to 44 on impacted areas. Maximum bacteria counts were obtained during periods of lower flows and warmer water temperatures.

Weibel et al (1966) included studies of pollution constituents in runoff from five agricultural lands. Runoff from a cultivated field in winter wheat that was free of farm animal wastes gave a BOD_5 of 7 mg/l. Nutrient levels from all five lands were many times the threshold levels associated with algae problems. Bacterial indicator densities were high in most farm land runoff samples. FS densities were greater than FC densities from areas subjected to farm animal wastes. The authors took this as an indication that the bacteria were predominantly from warm-blooded animals other than humans.

Miner et al (1966a) evaluated the runoff-carried water pollutants from feedlots. They encountered problems not applicable to domestic waste sources because runoff is intermittent and is seldom confined to a well-defined point. The runoff during and immediately after rainfall was found to be high strength organic waste containing considerable quantities of nitrogen. Concentrations of organic matter and nitrogen increased with low rainfall intensities, warm weather, and moist lot conditions. The amount of runoff from concrete lots was about twice that from nonsurfaced lots. Runoff was heavily loaded with bacteria normally used to evaluate water quality.

In reporting earlier work with Smith relative to water quality measurements on water courses receiving feedlot runoff, Miner et al (1966b) reported BOD_5 values rising from 2 mg/l to as high as 90 mg/l following rainfall. High ammonia concentrations in runoff were also noted. They found high bacterial counts and observed a decrease in the FC/FS ratio when feedlot runoff was present.

Grub et al (1969) discussed in a general manner the factors affecting the quality and quantity of runoff from feedlots. The factors given were: (1) precipitation; (2) surface material; (3) land slope; (4) depth of waste accumulation; (5) feedlot layout; and (6) ration composition.

Goleuke and Oswald (1966) indicated that the effluent from a strictly anaerobic manure pond is not in a condition suitable for discharge into surface waters since the BOD is excessively high (1100-3000 mg/l). Generally, they concluded that anaerobic ponds should not have any effluent.

Willrich (1966) and Curtis (1966) reported on the use of lagooning for treatment of swine wastes. As with most other papers written on animal waste disposal, primary emphasis was placed on freedom from odor and other nuisance conditions as criteria for satisfactory operation. Little or no mention was made of waste treatment to prevent water pollution. Although Curtis was a public health engineer with the Nebraska

State Department of Health, he cited only the following factors as indicators of a successful lagoon operation: (1) a relatively odor-free operation; (2) trouble-free water carriage of wastes away from animals; and (3) an economic life in balance with initial investment.

In an investigation of swine waste disposal in Illinois in 1963, Clark (1965) of the Illinois State Department of Public Health concluded that "lagoons" were totally unsatisfactory, malfunctioning, open digesters. The removal of solids by septic tanks and other means provided satisfactory operation at a loading of 230 pounds of COD per acre per day. Available information on swine waste strength was found to be unsatisfactory so waste characterization studies were made with the following results: BOD_5, 8200 mg/l; COD, 67,200 mg/l; TS, 33,000 mg/l; VS, 26,000 mg/l; volatile acids, 2,600 mg/l; coliform, 60 x 10^6/100 ml; enterococcus, 20 x 10^6/100 ml; pH, 6.5; NH_4, 500 mg/l; NO_2, neg; NO_3, neg; N (Kjeldahl), 0.12 mg/l; and K_2O, neg. BOD_5 tests were found to be unreliable because of antibiotic effects. Chemical oxygen demand tests were consistent and in general agreement with the 20-day BOD tests.

Loehr and Agnew (1967) and Loehr (1967) reviewed the literature on cattle wastes and reported on anaerobic and aerobic disposal systems. They concluded that the quantity and quality of wastes from beef feedlots are such that a combination treatment system may be the most successful. A combined anaerobic-aerobic lagoon system was thought to have significant potential. The effluent from anaerobic lagoons was found to be "potent" and required further treatment before discharge to a stream.

The successful disposal of liquid chicken manure by the plow-furrow cover method was reported by Reed (1966). Additional studies to determine the optimum capacity of the soil for manure disposal are underway.

In reporting on the requirements for microbial reduction of farm animal wastes, Berry (1966) cited the low temperature of the manure lagoon coupled with the high concentration of soluble materials as limiting factors in its success. He expressed the opinion that manure lagoons in the northern plains are at best primary settling basins with little opportunity for a sequence of bacterial action. He saw little to distinguish them from the domestic "seepage cesspools" used earlier in the century.

Work by Irgens and Day (1966) on the aerobic treatment of swine waste disclosed the following values for overflow from manure collection pits (anaerobic lagoons): BOD, 1910 to 2890 mg/l; PO_4, 370 to 475 mg/l, COD 4300 to 5200 mg/l and N, 650 to 750 mg/l. The authors affected a 95 percent reduction in BOD with seven days aeration of effluent in the laboratory. They have built oxidation ditches inside swine production buildings, utilizing a continuous gutter under the self-cleaning slotted floor. The effluent is then treated by secondary sedimentation before disposal.

Trickling filters were found to be an effective means of reducing the pollution qualities of dairy manure by Bridgham and Clayton (1966). Their experiments suggested a final sedimentation tank volume of about

114 ft^3/cow. A trickling filter system would require from 346 to 391 ft^3 of tanks per cow to produce an effluent BOD of 200 mg/l. (Note: The strength is still 2/3 that of raw human sewage.)

No satisfactory assessment has yet been made of animal wastes as a source of pollution of ground and surface waters. The approach to animal waste treatment has been limited to fragmentary attempts at waste characterization and nuisance prevention.

PROCEDURAL CONSIDERATIONS

No precedent was available for a study to determine the extent to which effluents from farm animal production areas contribute to stream pollution and to develop the factors necessary to predict the amount of pollution from these operations. Since the study was unique and differed greatly from previous pollution investigations, little help in developing the research plan was found from a literature search. Thus, schemes were proposed, tried, and modified as indicated by findings.

Representative animal production operations existing in the Piedmont Region of North Carolina were selected for study. The sites were free of other sources of wastes except background (natural) pollution. A control watershed free of domestic animal wastes was studied to define the natural pollutional loading expected from the study sites in the absence of animal production. Data detailing production and waste handling faciilities and practices were collected at each site. The amount of effluents, or stream flow, from the sites were continuously measured. Samples of the effluent from each site were collected and analyzed to determine waste concentrations during warm and cool periods and before and during periods of surface runoff.

Determination of Representative Animal Production Operations

Nine North Carolina County Extension Offices (Wake, Chatham, Randolph, Johnston, Wilson, Edgecombe, Duplin, Harnett, and Cumberland) were visited to obtain an understanding of the representative practices of farm animal production and waste management. The major animal producers throughout the counties were also visited.

The principal types of swine operations contributing to surface water pollution were judged to be lagoons with surface outflow, drylot operations, particularly those that allowed swine access to streams, direct discharge of wastes from confinement growing areas to streams, and drainage from areas used to receive wastes by spreading.

Representative dairy operations washed wastes from the milking parlor into streams or drainage paths leading directly to streams. Some solids were usually removed and spread on surrounding pastures.

The beef operations were primarily brood cow operations. Cattle were generally pastured throughout the year and normally had direct access to streams.

Two types of poultry operations, with respect to waste handling, were found to be common in the counties visited. In one type, shavings were added to the wastes (usually broiler operations but also a large number of egg-production systems) while in the other no litter was added. Both types of operations disposed of wastes by land spreading.

Site Data Collection Plan

Data were collected from each production site to ascertain the amount and strength of wastes produced and methods of waste disposal. The following data were included: (1) description of animal-growing facilities, including waste handling facilities and practices; (2) number and size of animals; (3) type and composition of feeds, including additives; (4) vegetation and cultural practices; (5) description of drainage system from the production/disposal area to surface waters; and (6) soil classification. Data for items 1-4 were supplied by the animal operators on a monthly basis. When wash-water was used, the quantity was estimated by measuring the rate of nozzle discharge and the period of wash-down. Soil classifications were obtained from reports by the Soil Conservation Service.

The hydrological data obtained for each area were: (1) rainfall intensities and amounts, (2) amount of effluent or streamflow, and (3) daily maximum and minimum air temperature. Water temperature measurements were made when the sampling stations were visited. Rainfall was measured at each site using recording rain gages. Flow measurements were made with H-flumes and water-level recorders. These data were continuously recorded throughout the study periods. Temperature data were from reports of the State College Weather Station, Raleigh, N. C.

Flow-through measurements for the lagoons were made during February 1969. Flourescent dye (Rhodamine B) added to the influents of the lagoons appeared in the effluents after one or two hours. The monitoring was done with a 111-000 Turner Flourometer. The concentration of dye in the effluent gradually increased and peaked after five hours at site A and eight hours at the other sites. There was a very prolonged drop-off in dye concentrations at all three lagoons.

Attempts made to determine the time of flow from land areas receiving wastes to nearby streams were unsuccessful. Dye was applied to the soil surface in the case of pasture operations and mixed with the waste in the case of land spreading. The fluorometer reading of the small amount of dye that may have reached the monitoring point in a stream was confounded with an increase in background reading caused by an increased sediment load carried by the stream during periods of surface runoff.

Site Description and Management Practices

All twelve study areas were located in the Piedmont Region of North Carolina near Raleigh. No change from the operator's normal practices of either production or waste management was made for the study.

Swine Sites

Seven swine production sites were studied. Lagoons were used for waste disposal at three of the sites, A, B, and C. Each lagoon had a continuous surface discharge except during periods of prolonged absence of rainfall. Swine sites, D, E, F, and K, were located in watersheds

in which small streams originated. They included direct discharge of wastes to a stream, waste disposal by land spreading, and an animal-free control watershed.

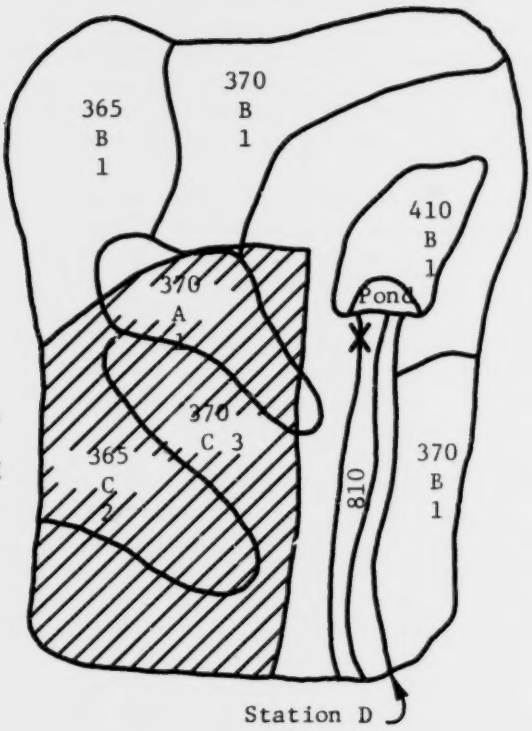
The rations fed the swine were basically finely ground yellow corn supplemented to contain about 15 percent protein, 0.7 percent calcium, and 0.55 percent phosphorus. The feeds contained additives of mineralized swine salt, vitamins, antibiotics, arsenicals, and antioxidants. A particularly high rate (>1 lb per ton) of copper sulphate was commonly used. Cooked garbage was also fed at site A.

Site A. The lagoon at site A had been in use for six years and served an average of 300 hogs from feeder-pig size (40 lbs.) to market size (225 lbs.). It averaged five feet in depth and had a surface area of approximately 50,000 ft^2. The lagoon received drainage from an additional 20,000 ft^2 of surface area. The hogs were grown in confinement on concrete and wastes were washed from the growing area each day. Wash water averaged about 15 gal/day/hog. An estimated additional 15 gal/day/hog was added to the lagoon from leaky valves and swine wastes. The topsoil and subsoil in the area were tight clay.

Site B. Lagoon B was three years old and served an average of 100 hogs from feeder to market size. It was six feet in depth and about 20,000 ft^2 in surface area. An additional 10,000 ft^2 drained into the lagoon. The hogs were grown in confinement on concrete and wastes were washed from the growing area each day. The wash water averaged about 10 gal/day/hog. The subsoil in the area was heavy clay and the topsoil was a sandy loam.

Site C. Lagoon C was two years old, eight feet deep, and 20,000 ft^2 in surface area. It drained an additional 5,000 ft^2. The average hog population previous to and during the study was 90. The hogs were grown in confinement on concrete. Wash water was about 10 gal/day/hog. During the cooler months, wastes were retained in a trench under the hog house for periods as long as two weeks before being dumped into the lagoon. The lagoon was located in a tight clay soil.

Site D. At site D, wastes from a farrowing house, pens holding feeder pigs, and runoff from lots used to pasture brood hogs entered the stream that originated in the basin. The house and pens had concrete floors. Water for drinking purposes flowed continuously through the house and pens from a farm pond located at the head of the stream. The wastes produced in the confined growing areas were washed directly into the stream, normally every two days. The lots were about 10 acres in size and were located on the steeper part of the watershed. Figure 1 is a map of site D including soil types, slopes, and sampling station location. About 70 percent of the area was void of vegetation. Small gullies were predominant throughout the lots. The total drainage area above the sampling point was about 40 acres. Corn and tobacco were grown on 20 acres of the better land, and the remaining area was in woodland and farm roads.



NOTE: Shaded area is area of drylots. X is dumping site.

SOIL CLASSIFICATION LEGEND

365B1 - Norfolk sandy loam, 2-6% slope, slightly eroded

365C2 - Norfolk sandy loam, 6-10% slope, moderately eroded

370A1 - Norfolk loamy sand, 0-2% slope, slightly eroded

370B1 - Norfolk loamy sand, 2-6% slope, slightly eroded

370C3 - Norfolk loamy sand, 6-10% slope, severely eroded

410B1 - Goldsboro sandy loam, 2-6% slope, slightly eroded

810 - Mixed local alluvial land, poorly drained, nearly level

Figure 1. Map of site D

The production area had been used two years prior to beginning the study. However, about eight months before the start of the study all swine had been removed because of a disease problem. New brood stock were obtained shortly thereafter, but the farrowing house and holding pens were not used until farrowing began at the onset of the study. The brood sow population averaged 150 on the lots and 50 in the farrowing house during the study. After the first month of study an average of 450 feeder-size pigs were housed in the holding pens.

Site E. A small stream originated at the head of a gully at site F. About five acres of the 35-acre drainage basin above sampling station E were used to spread the wastes from swine growing in houses with partially slotted concrete floors. The remainder of the watershed was in grass (10 acres), small grains (5 acres), corn (10 acres), and orchards (5 acres). No farm animal wastes had been deposited in the study area for six months before the study began. The only wastes on the watershed prior to this was droppings from beef grazing the disposal area. A liquid manure spreader was used to pump the wastes from the 4-ft. by 4-ft. ditches under the houses and to spread it on the grassed disposal area. A minimum amount of water was used in the houses and the wastes were removed from the pits only as they became filled. Normally, a portion of the manure was removed every two weeks.

When spreading began, about 200 hogs averaging 100 lbs. in size were being grown to market size. After they were removed, another group of about 500 were farrowed and finished out in the houses. The cumulative rainfall and wastes spread between December 1, 1968, and June 18, 1969, are represented in Figure 2. During this period the waste application rate averaged about 4,000 gal/acre/mo. Three acres of lots for brood sows were established in the drainage basin during the study period. Eighty-six sows and 100 gilts were moved to the lots on February 20, 1969, and this number remained on the lots throughout the remainder of the study period. The lots were well grassed initially, but had begun to show some bare spots by June 1969. Figure 3 is a map of site E including soil types, slopes, and sampling station location.

Site F. A small stream originated in the 75-acre basin above site F, the control site. Site F was adjacent to site E and was devoid of domestic animal wastes. No farm animal wastes had been spread or deposited on the area for six months prior to the study period. The basin consisted of 25 acres of grassed pasture, 20 acres of wood pasture, 20 acres of corn land, and 10 acres of orchard. About two acres was swampy. Figure 4 is a map of site F including soil types, slopes, and sampling station location.

Site K. A stream originated in the basin at site K. At the beginning of the study, the site was subjected to domestic animal wastes from three acres of drylot pasture holding 150 brood sows that had access to the stream. The pasture had been in use for six months before sampling began and was woodland with little surface cover other than large trees. The pasture area was steep and had small gullies throughout. Just prior to beginning the study, three acres of additional lots were established in the basin. This area was well covered in grass and was gently sloping.

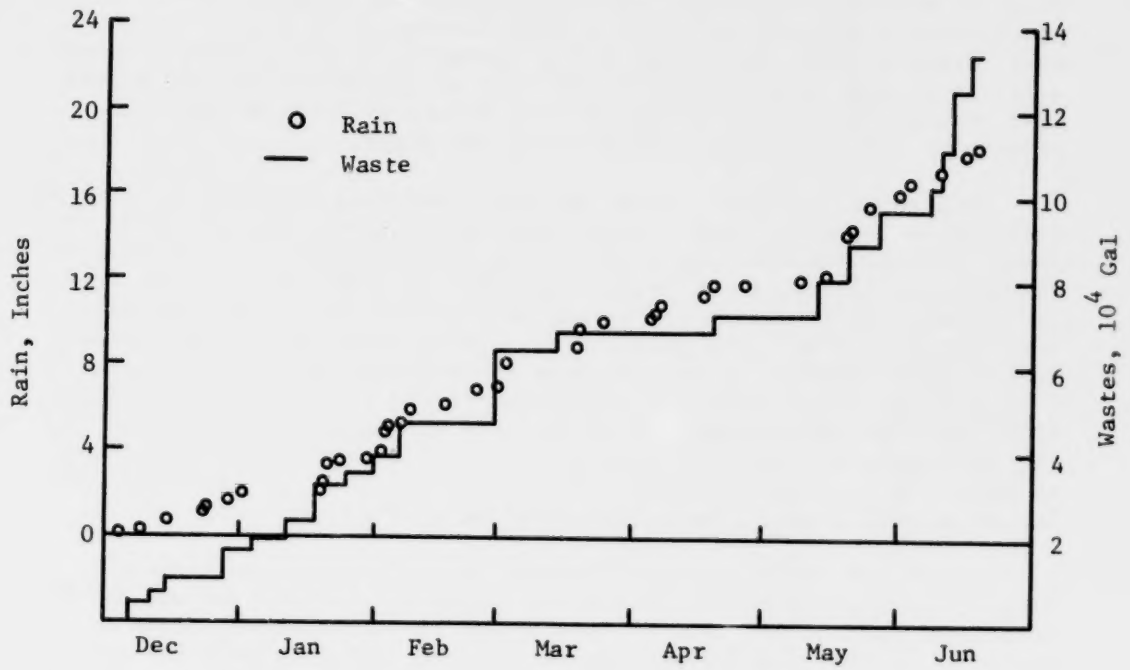
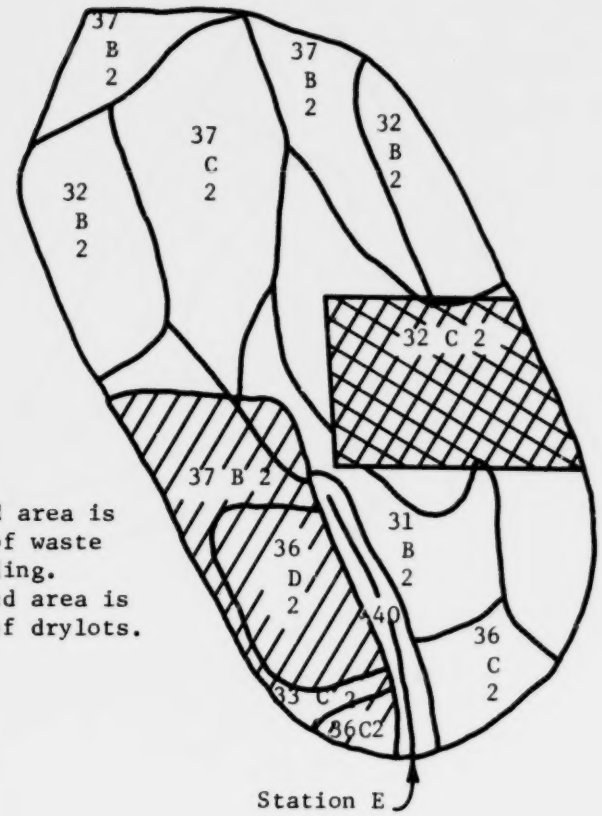


Figure 2. Rainfall and amount of swine wastes spread on site E

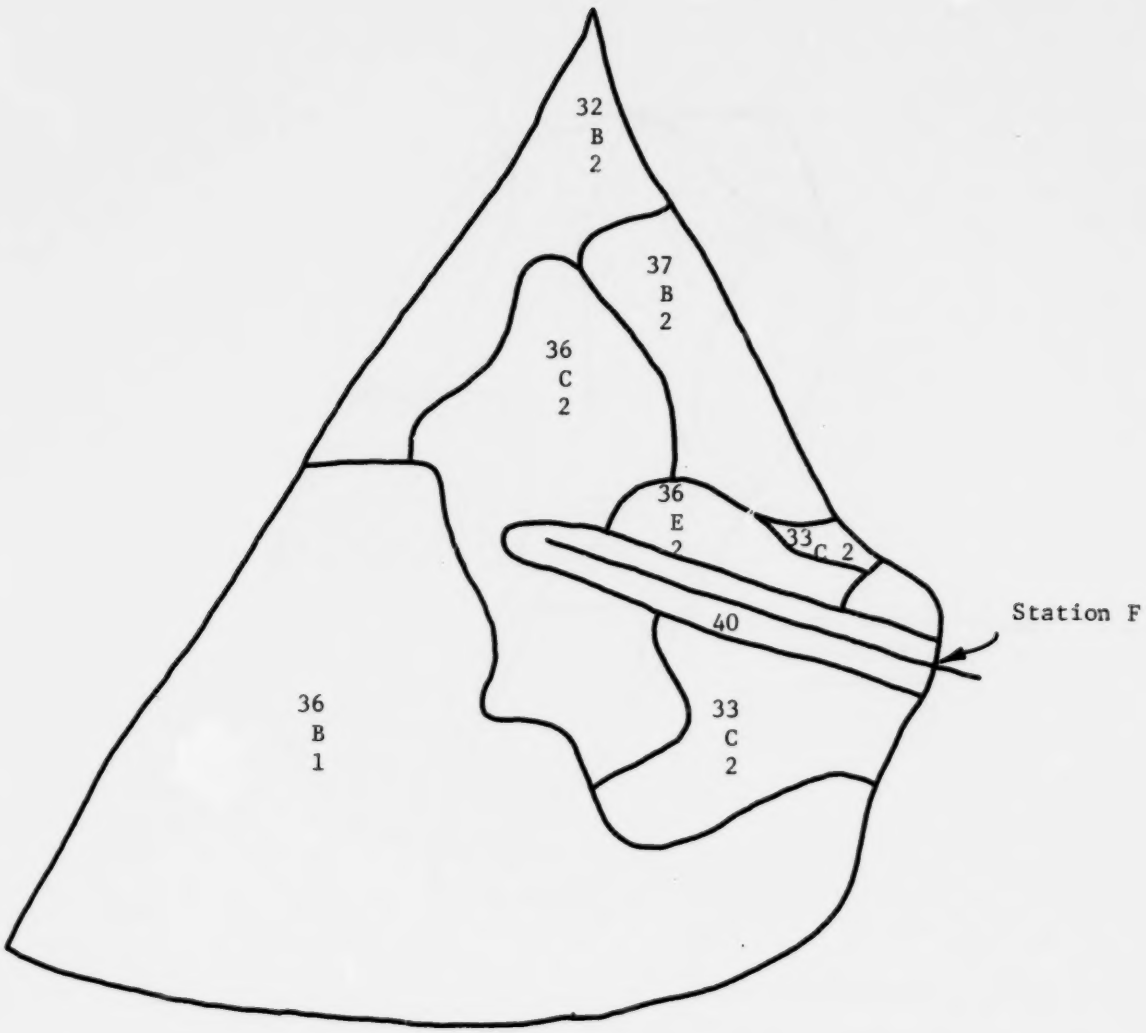


NOTE: Shaded area is area of waste spreading. Hatched area is area of drylots.

SOIL CLASSIFICATION LEGEND

31B2 - Cecil sandy loam, 2-6% slope, moderately eroded
32B2 - Cecil fine sandy loam, 2-6% slope, moderately eroded
32C2 - Cecil fine sandy loam, 6-10% slope, moderately eroded
33C2 - Cecil gravely fine sandy loam, 6-10% slope, moderately eroded
36C2 - Applying sandy loam, 6-10% slope, moderately eroded
36D2 - Applying sandy loam, 10-15% slope, moderately eroded
37B2 - Applying fine sandy loam, 2-6% slope, moderately eroded
37C2 - Applying fine sandy loam, 6-10% slope, moderately eroded
40 - Colfax sandy loam

Figure 3. Map of site E



SOIL CLASSIFICATION LEGEND

32B2 - Cecil fine sandy loam, 2-6% slope, moderately eroded
33C2 - Cecil gravely fine sandy loam, 6-10% slope, moderately eroded
36B1 - Applying sandy loam, 2-6% slope, slightly eroded
36C2 - Applying sandy loam, 6-10% slope, moderately eroded
36E2 - Applying sandy loam, 15-25% slope, moderately eroded
37B2 - Applying fine sandy loam, 2-6% slope, moderately eroded
40 - Colfax sandy loam

Figure 4. Map of site F

The total hog population in the basin reached 250 near the end of the study. The remaining drainage area included about 20 acres of tobacco and other row crops, 5 acres of unused grassland, and 20 acres of woodland. Figure 5 is a map of site K including soil types, slopes, and sampling station location.

Dairy Sites

Two similar dairy sites were studied. Both operations washed liquid wastes from the milking parlor into drainage paths leading to small streams which originated in the basins. Solids removed from the parlors were spread on surrounding pastures. These drained into the streams receiving wastes directly from the parlors.

Site H. The area at site H had been converted from row crops to a dairy operation six months before the study began. The number of dairy animals contributing wastes to site H was as follows:

Month	Milking	Dry	Heifer > 1 yr	Heifer < 1 yr
April	61	3	4	12
May	63	1	3	26
June	64	1	12	16
July	50	14	22	16
August	44	22	27	9
September	58	16	14	8
October	58	20	12	0
November	45	18	11	0
December	54	12	8	0
January	60	8	6	0

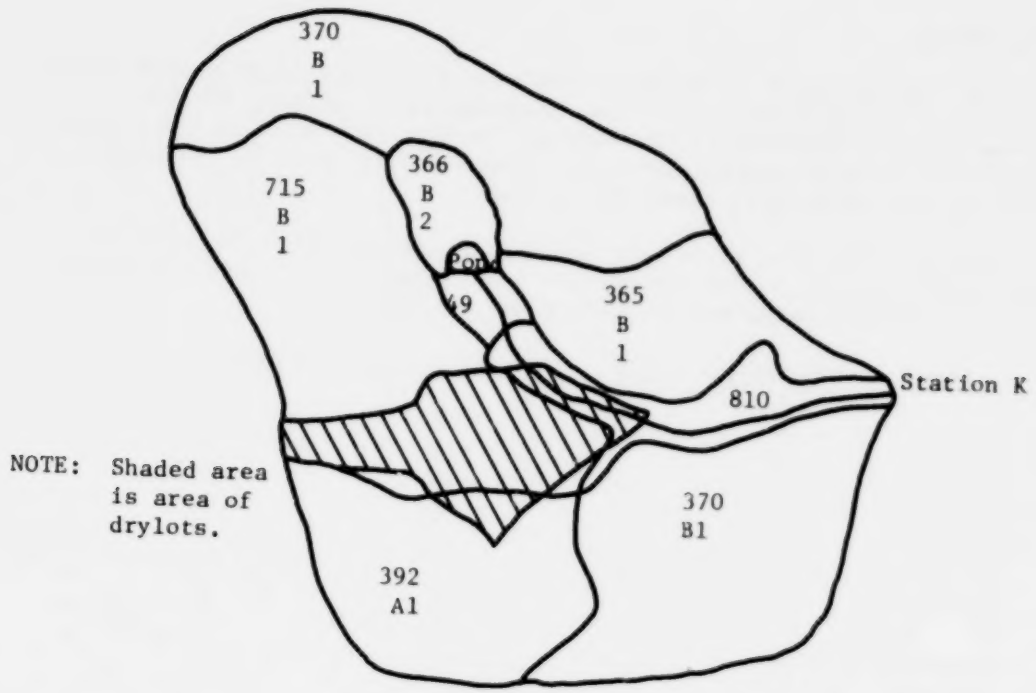
During April-August 1969, 8 tons/mo of 16 percent dairy ration and 40 tons/mo of corn silage were fed to the milking cows. During September-January, 15 tons/mo and 60 tons/mo, respectively, were fed. Hay consumption averaged 20 tons/mo throughout the study period.

An automatic scraper was used in the dairy parlor to remove solids to a manure spreader.

The 70-acre watershed above station H consisted of 55 acres of pastures and 15 acres of corn land. Figure 6 is a map of site H including soil types, slopes, and sampling station location.

Site J. The area at site J had been used as a dairy for more than 10 years. An average of 110 milking cows, 15 dry cows, and 36 heifers were kept in the 15-acre watershed. All but two acres (domestic dwellings and shops) were pasture and barnyard. Figure 7 is a map of site J including soil types, slopes, and sample station location.

Feed composition averaged 20 tons/mo of 3/4 part ground corn and 1/4 part 44 percent soybean, 360 tons/mo of sorgham sileage, 200 tons/mo of corn sileage, and 10 lb/day/cow of orchard and/or alfalfa hay.

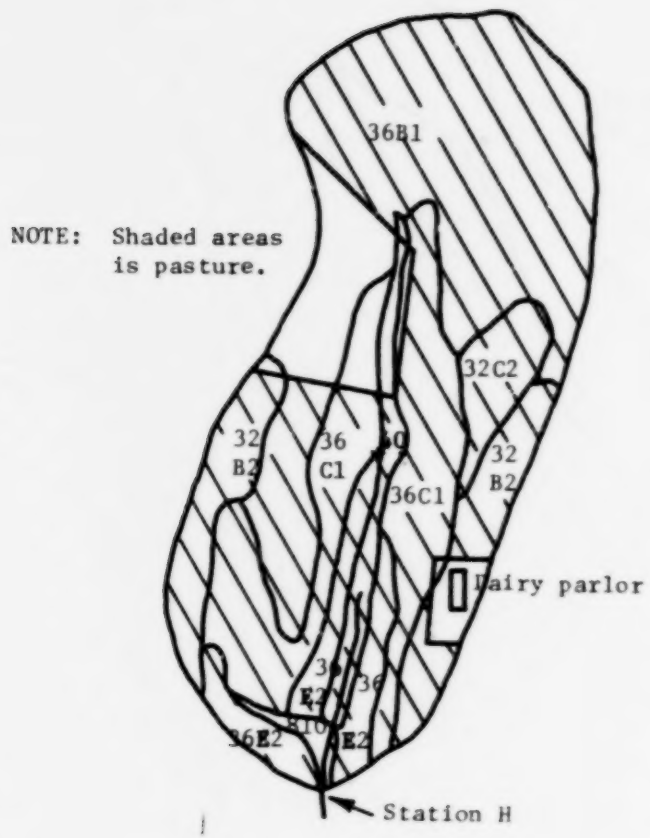


NOTE: Shaded area is area of drylots.

SOIL CLASSIFICATION LEGEND

365B1 - Norfolk sandy loam, 2-6% slope, slightly eroded
366B2 - Norfolk fine sandy loam, 2-6% slope, moderately eroded
370B1 - Norfolk loamy sand, 2-6% slope, slightly eroded
392A1 - Fuquay (Wagram) loamy sand, 0-2% slope, slightly eroded
49 - Mixed local alluvial land, moderately well drained
715B1 - Lakeland loamy sand, shallow phase (30-42 in.), 2-6% slope. slightly eroded
810 - Mixed local alluvial land, poorly drained, nearly level

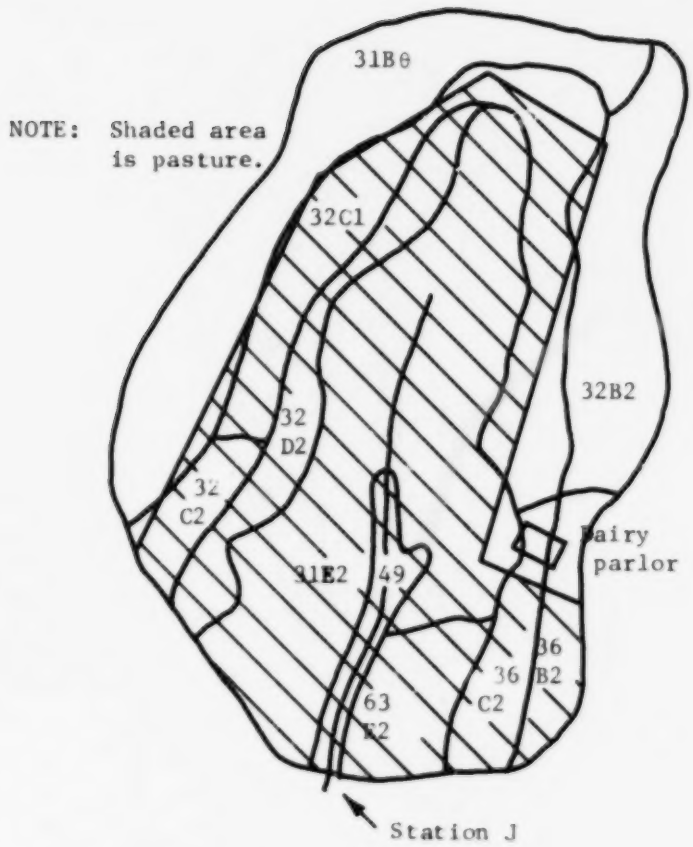
Figure 5. Map of site K



SOIL CLASSIFICATION LEGEND

(See Figures 1, 3, and 4.)

Figure 6. Map of site H



SOIL CLASSIFICATION LEGEND

31B0 - Cecil sandy loam, 2-6% slope, buildings
31E2 - Cecil sandy loam, 15-25% slope, moderately eroded
63E2 - Wilkes loam, 15-25% slope, moderately eroded

See Figures 3, 4, and 5 for other descriptions.

Figure 7. Map of site J

An exceptionally poor job was done of removing solids from the milking parlor before wash-downs, and a larger portion of the wastes were washed directly into the receiving stream than from site H.

Poultry Sites

Two areas receiving wastes from egg production operations were studied. The feed used was a standard ration in both operations, i.e.,

Corn	1200 lb
Soybean	400 lb
Meat scrap	60 lb
Fish meal	50 lb
Alfalfa	60 lb
Limestone	120 lb
Phosphate	40 lb
Premix vitamins	5 lb
Salt	8 lb
Corn fermentation	50 lb

About one-third of the feed had pro-strep, penicillin/streptomycin. Feed consumption averaged 110 lb/yr/hen.

Site P. Shavings were mixed with poultry wastes spread on site P. Wastes were applied to the 65-acre watershed three times per year from three houses containing 3500 laying hens each. Each house was cleaned once per year and the wastes were applied to about five acres. The watershed had been used for waste disposal for more than ten years.

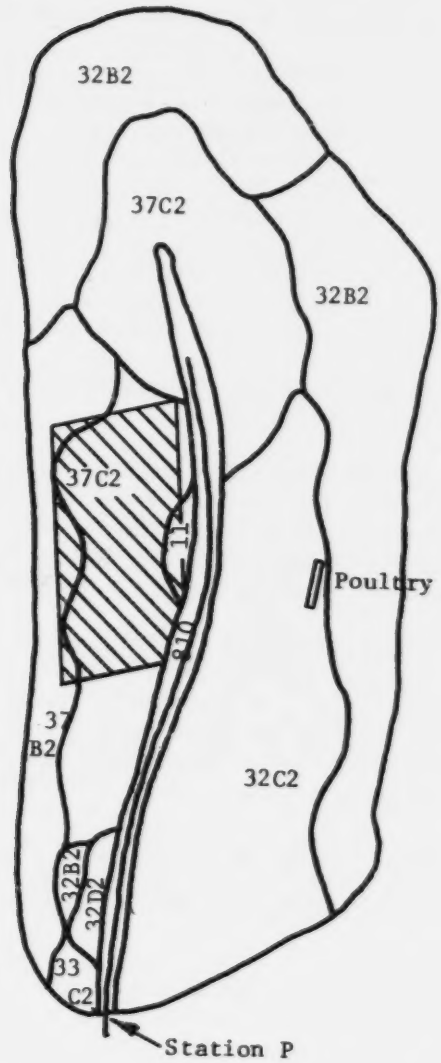
During the study, wastes were spread on the watershed twice. The first spreading was during the first week of October, 1969. The second was on January 13-14, 1970. The rate of spreading was about four tons per acre and spreading was on row and cover cropped fields, away from meadow strips and other well-defined drainage areas. Figure 8 is a map of site P showing soil types, slopes, and sampling station location.

Site X. Figure 9 is a map of site X showing soil types, slopes, and sampling station location. The station was located in a meadow strip draining the surrounding fields which had been turned during the fall of 1969.

Twenty-two tons of fresh poultry waste, not containing litter, were spread on four acres of the five-acre watershed above station X on February 10, 1970. The waste was spread on the plowed fields and in the meadow strips. It weighed one ton/yd^3.

Beef Site

Site Z was studied to determine the amount of pollution reaching streams from beef pastures. Figure 10 is a map of the watershed above station Z and shows the soil types and slopes. Fifteen acres of the 25-acre watershed were in pasture. The remaining area was woodland and idle land. A small stream originated at the head of a gully in the pasture.



NOTE: Shaded area is area of waste spreading.

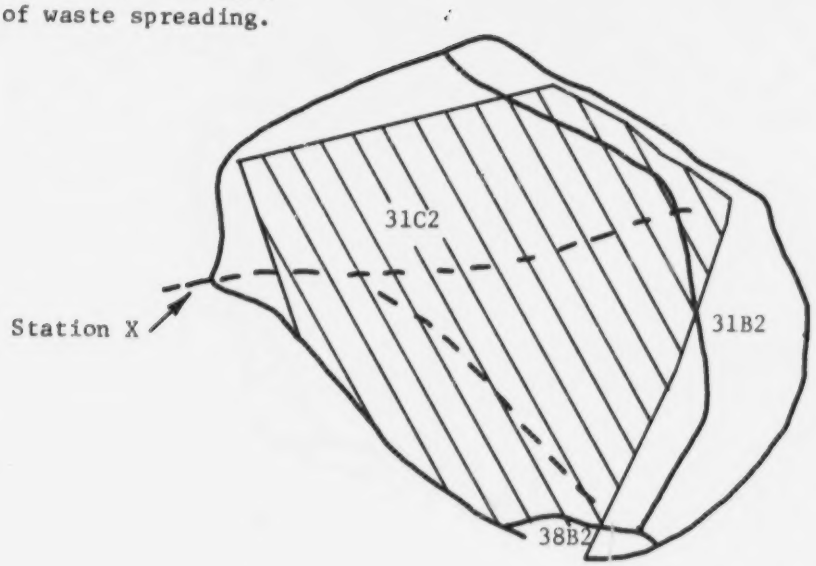
SOIL CLASSIFICATION LEGEND

11 - Local alluvial land, sandy

See Figures 1 and 3 for other descriptions.

Figure 8. Map of site P

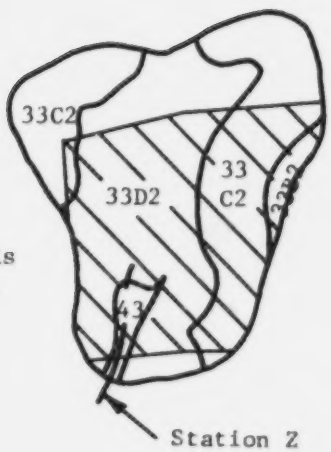
NOTE: Shaded area is area of waste spreading.



SOIL CLASSIFICATION LEGEND

31B2 - Cecil sandy loam, 2-6% slope, moderately eroded
31C2 - Cecil sandy loam, 6-10% slope, moderately eroded
38B2 - Appling gravelly sandy loam, 2-6% slope, moderately eroded

Figure 9. Map of site X



NOTE: Shaded area is pasture area.

SOIL CLASSIFICATION LEGEND

43 - Chewcla fine sandy loam, 0-6% slope

See Figure 3 for other description.

Figure 10. Map of site Z

Twenty-three beef cattle averaging 500 lb live weight were placed in the pasture during October 1969 two months before sampling began. The area was void of farm animal wastes during the proceeding eight months. During January 1970 an additional 26 beef animals that averaged 600 lbs. each were placed in the pasture until the end of the study, May 1970. Most of the animals were heifers and were fed hay, silage, and some ground corn and soybeans to sustain them through the winter.

Twelve samples were also collected from the stream at site F, the control watershed, during a runoff period in late August 1970 two weeks after 34 beef animals were placed in the pasture. These data are not reported since the study period was short and waste accumulation small. No change was noted in the quality of the water due to this small number of animals per unit area of the watershed.

Sample Collection Plan

More than 1500 samples of the effluent from the twelve study areas were collected in iced containers by automatic samplers described in Appendix A. The samplers were started manually for the lagoon studies and automatically when the water level rose to a predetermined level for the stream studies. Once sampling was started, samples were collected at selected time intervals. A common sample interval was two hours.

Samples were removed from the sample containers as soon as feasible (within 24 hours) after collection and returned to the laboratory for analysis. Samples collected manually were delivered to the laboratory immediately. A number of samples were duplicates; i.e., two samples collected at the same time to make procedural checks. Occasional samples were composited before analyses.

Swine

Swine waste management practices involved include the three basic means used to handle animal wastes in the Piedmont Region of North Carolina; i.e., land disposal, lagooning, and direct discharge into streams. Since installation of equipment was simpler at the lagoon sites and sample collection was less dependent upon rainfall, sampling of the lagoon effluents was started first in October 1968. This permitted an early check-out of equipment and analytical techniques as well as providing the required data from the sites. Sampling of lagoons B and C was discontinued after the spring of 1969. The sampling at site A was continued through the summer of 1969. Most lagoon samples were collected during October, November, February, and March. About 50 percent were collected on an hourly basis. Sampling during other periods was generally on a weekly or bi-weekly basis. The numbers of samples taken from the outflow from the lagoons and analyzed were 179 at site A, 90 at site B, and 107 at site C. Fourteen grab samples of the inflow to the lagoons were also collected.

Sampling at sites E and F began in December 1968 and was continued until July. About one-fourth of the samples from these sites were collected during periods of no surface runoff. These were used to evaluate changes in water quality of the base flows as well as changes in water

quality caused by surface drainage. The number of samples collected at site E was 176 and at site F 148. Eighteen samples of the wastes being spread on site E were also collected.

Sampling at station D began in March 1969 and was continued through June. About one-half of the 117 samples were collected during periods of no surface runoff. The samples were used to evaluate the load on the stream caused by direct discharge of wastes from the farrowing house and holding pens and to provide a base for establishing the contribution from the drylots during periods of surface runoff.

At station K, 100 samples were collected from April to August 1969. About one-fourth of the samples were collected during periods of no surface runoff to ascertain the base flow quality, to measure contributions from swine having access to the streams, and to aid in evaluating the loadings during periods of surface runoff.

Dairy

Sampling at site H began in June 1969 and continued to January 1970 while the study at site J covered the period from October 1969 to April 1970. About one-fourth of the samples from each of these sites were collected during periods of no surface runoff. These provided a means to evaluate pollution caused by washings from the milking parlors and to provide a base for establishing the contribution from the pastures during periods of surface runoff. The number of samples collected from site H was 126 and that from site J 102.

Poultry

At site P, 108 samples were collected between June 1969 and April 1970. About one-fourth of these were collected during base-flow conditions and provided a basis for evaluating the changes in water quality of the base flows with time as well as changes in the stream quality caused by surface runoff.

Sampling at site X began in February 1970 before wastes were spread and continued through April 1970. The predisposal samples were collected to determine the natural pollution load. Samples were collected during the first runoff period shortly after the spreading operation to ascertain the maximum contribution expected from land disposal of poultry wastes. Subsequent samples were collected in April to determine the decay of pollution with time after spreading.

Beef

At site Z, 78 samples were collected from November 1969 to April 1970. About one-fourth of these were collected during periods of no surface runoff to ascertain the base flow quality, to measure contributions from beef animals having access to the stream, and to aid in evaluating the loadings during periods of surface runoff.

Analyses of Samples

Generally, the analyses performed on the samples were according to procedures described in Standard Methods (APHA, 1965). Analyses performed on a particular sample were in keeping with the objectives of the study and the work load in the laboratory. A full-time technician performed all tests except nutrient analyses. Analyses for the phosphorus and nitrogen series were performed by the North Carolina Department of Water and Air Resources using an Auto-Analyzer.

Analyses included the following:

1. Total coliform (TC), colonies/100 ml.
2. Fecal coliform (FC), colonies/100 ml.
3. Fecal streptococci (FS), colonies/100 ml.
4. Biochemical oxygen demand (BOD), mg/l.
5. Chemical oxygen demand (COD), mg/l.
6. Total solids (TS), mg/l.
7. Volatile solids (VS), mg/l.
8. Total organic carbon (TOC), mg/l.
9. Kjeldahl nitrogen (TN), mg/l.
10. Ammonia nitrogen (NH_3), mg/l.
11. Nitrite nitrogen (NO_2), mg/l.
12. Nitrate nitrogen (NO_3), mg/l.
13. Total phosphate (TP), mg/l.
14. Orthophosphate (OP), mg/l.

Specific conductivity and pH measurements were also made on several samples. The following pollution indices were determined to be most suitable for delineating the quality of the samples and were the principal analyses performed during heavy laboratory workload periods: (1) FC; (2) BOD_5; (3) TOC; (4) TN; and (5) TP.

Standard Analyses

Density of bacteria indicator organisms was measured by the membrane filter procedure (Taylor et al, 1955). TC counts were made using M-Endo medium and incubation at 35°C for 24 hr (Kabler and Clark, 1960). FC counts involved incubation at 44°C for 24 hr and a M-FC medium (Geldreich et al, 1965). KF medium was used for FS measurements with incubation at 35°C for 48 hr (Kenner et al, 1961). Although primary reliance was placed on the FC to indicate bacterial contamination, a large number of samples from the swine sites were analyzed for TC because of the wide acceptance of this test. Because the FC/FS ratio had been suggested as an indicator of waste origin (Geldrich, 1966), a few FS measurements were made.

Because several investigators, e.g. Clark (1965), had reported difficulties in using the BOD parameter to characterize animal wastes, plans were made to place primary reliance on TOC values once BOD/TOC relationships were determined. However, poor BOD results for the lagoon samples made establishment of any BOD/TOC relationships questionable and the decision was made to continue the BOD throughout the study (Robbins et al, 1969a).

Most BOD tests were standard, five-day, 20°C, unseeded, determinations. Seeding and long-term tests were performed on a few samples. A Weston and Stack dissolved oxygen meter was used to measure the dissolved oxygen in most BOD tests. This was calibrated and checked with the Winkler method. BOD results were found to be dependent on the amount of sample used, particularly for the more polluted samples. Usually, the results showed higher BOD values in greater dilutions. Although these BOD variations were discovered early in the study, a thorough review of procedures failed to account for them in terms of procedural errors. The variations were attributed to the characteristics of the test and of the wastes. Multiple tests and additional dilutions (above the standard three) were performed on most samples collected after November, 1968. Some samples were analyzed for BOD immediately after collection and after one to six months of frozen storage.

Determinations of TS and VS were made on more than 100 lagoon samples. Because of low solids contents, solids tests on stream samples proved too inaccurate to be of use in assessing the amounts of wastes reaching the streams and were not generally performed on these samples.

Although not included in the early scheme of data collection, COD analyses were performed on about fifty of the lagoon effluent samples. Since good correlations between COD and TOC existed for samples of influents and effluents of the lagoons, the COD test was performed only as the heavy laboratory workload permitted. Often the COD values of the stream samples were too low to allow the test to be used as a tool for monitoring the contribution of wastes to the streams. However, the COD test was quite applicable to the more polluted stream samples and was used rather extensively during the dairy, beef, and poultry studies.

Total Organic Carbon Analyses

Two basic avenues toward estimating the oxygen demand of animal wastes are: (a) to determine the amount of oxygen or equivalent oxidant required to react with the organic materials, and (b) to measure the amounts of oxygen-demanding materials in the wastes. BOD and COD tests employ the oxygen-based approach. While both have wide acceptance, they have major inherent limitations. The TOC analysis offers many potential advantages for the measurement of organic waste substances. It eliminates many of the variables that confound oxygen-based tests, particularly the BOD tests, and produces more reliable and reproducible results. There are potential savings in analytical time and expense when the TOC test is used. A distinct advantage is the reduced time lag between sample collection and analysis. It also provides a carbon balance procedure that is useful in characterizing and following the decomposition of waste organic substances with time and treatment. The major limitation of the TOC analysis is the fact that the results are unfamiliar to investigators and a correlation of carbon-based results and oxygen-based results is necessary if it is to have direct use for waste characterization and water quality monitoring.

Until recently, the measurement of low concentrations of carbon in aqueous solutions was difficult and time consuming. For example, the

BOD test has been used to approximate carbonaceous matter in waste waters (Van Hall and Stenger, 1964). However, new TOC analyzers that provide a rapid and simple means for determining organic carbon levels in aqueous samples are now available (Van Hall and Stenger, 1967).

A Beckman Model 915 TOC Analyzer was used in this study. There were no operational problems except for the optional air purification unit which proved unsatisfactory because of a failure of the diaphragm in the air pump after a short period of use. This caused improper flow and pressure conditions to exist in the analyzer and necessitated the use of a bottled source of zero grade air.

The syringe used for measuring and injecting the sample into the TOC analyzer has a needle opening of 170μ in diameter and the sample volume is small, generally 20μl. Thus, blending is necessary for samples containing suspended material in order to prevent the screening out of large particles and to assure uniformity of samples (Schaffer et al, 1965). Since the peak value depends on the rate of sample injection as well as the carbon content of the sample, the rate of injection must be uniform for each determination.

Sample dilution with carbon-free water is necessary when carbon concentrations are greater than 4000 mg/l (maximum range of analyzer) or when high contents (10,000 mg/l) of salt, acid, or base anions are present (Ford, 1968a). A high anion content interferes with the infrared energy absorption pattern.

Nutrient Analyses

Because of delays in receiving the Auto-Analyzer equipment and of heavy laboratory workloads, most samples had to be stored a month or more before nutrient analyses were performed. Some were stored as long as six months before all analyses were made. At first, mercuric chloride, $HgCl_2$, was added to the samples (Jenkins, 1967) followed by refrigeration for preservation. The method was abandoned because the $HgCl_2$ caused a precipitate to form in the lagoon samples. This tended to clog the tubing of the Auto-Analyzer. Freezing was used on all other samples from the swine sites and proved to be satisfactory although not ideal. Five ml of chloroform was added per liter to all samples from the dairy, beef, and poultry sites before freezing the samples. Three portions of each sample were frozen so the tests could be performed on newly thawed samples. Some samples were refrozen and later thawed and tested again. There were occasional apparent changes in nutrient contents of samples without chloroform handled in this manner. Also, when the lagoon samples were thawed, insoluble precipitates not observed before freezing were present.

Commonly used Auto-Analyzer methods for determining TN, NO_2, NO_3 and OP proved quite reliable. TP and NH_3 analyses of the lagoon wastes presented difficulties until appropriate methods were found to handle samples with considerable particulate matter. A method using a continuous digestor gave good TP results. A dializer was used in the NH_3 determination to eliminate the solids problem. This technique gave good results.

In all tests alternate samples of water were used for washout of the flow system. This gave an effective rate of sampling of one-half the recommended rate. Every tenth sample was a standard. All Auto-Analyzer determinations conformed to procedures described in Standard Methods (APHA, 1965). Checks made against the manual determinations gave the same results within the expected accuracy of each test.

Total Nitrogen. TN, as used herein, is total Kjeldahl nitrogen. It is the sum of the free ammonia and organic nitrogen compounds that are converted to ammonium sulfate under the conditions of digestion which are specified below.

Basically, the quantitative determination of TN was per Technicon Corporation (1965) Bulletin N-3 and the FWPCA (1969) automated phenolate method. It involved complete digestion of organic material followed by measurement of the quantity of ammonia produced. The samples were automatically digested using an Auto-Analyzer continuous digestor and a sulfuric acid solution containing perchloric acid and vanadium pentioxide as a catalyst to convert organic nitrogen to $(NH_4)_2SO_4$. The solution was then automatically neutralized with sodium hydroxide and treated with alkaline phenol and sodium hypochlorite. This treatment formed a blue-green color designated as indophenol and was measured colorimetrically. Sodium nitroprusside was used to increase the intensity of the color for samples containing low levels of TN (FWPCA, 1969. Brij-35 detergent was added to the alkalin phenol reagent at the rate of one-half ml/l to improve the flow patterns.

Ammonia. The Auto-Analyzer procedure used to determine NH_3 concentrations in the samples was the alkaline phenol-hypochlorite method proposed by O'Brien and Fiore (1962). Brij-35 detergent was added to the sodium carbonate and sodium phenate reagents at the rate of one-half ml/l to improve the flow patterns and prevent plugging of the flow system. Methods not employing a dialyzer were not as satisfactory as the one used. The samples usually contained a large amount of particulate matter even after filtering with a continuous filter. This caused erratic flow patterns in the system and poor results.

Nitrite-Nitrate. The Auto-Analyzer procedure used to determine NO_2 and NO_3 contents of the samples was similar to the adaptation of the diazotization method proposed by Kamphake et al, (1967). Under alkaline conditions the NO_2 ions reacted with sulfanilamide to yield a diazo compound that coupled with N-1-naphthylethylene-diamine dihydrochloride to form a soluble dye which was measured colorimetrically. All NO_3 in a sample was first reduced to NO_2 by an alkaline solution of hydrazine sulfate containing a copper catalyst for NO_2 plus NO_3 measurements. Subtraction of the NO_2-N originally present in the sample from the total NO_2-N found after reduction gave the original NO_3-N concentration. One-half ml of Brij-35 detergent was added to each liter of color reagent to improve flow patterns. When NO_3 was not measured, the copper reagent and hydrazine sulfate inlet lines were placed in water and the heating bath was by-passed.

Total Phosphate. The procedure used to measure TP contents of the samples first converted the phosphates present to orthophosphate by using

the Kjeldahl digestion procedure reported above. The phosphate concentration was then determined by the reduction of phosphomolybdic acid with aminonaphtholsulfonic acid (ANSA) as proposed by Lundgren (1960) for determining total inorganic phosphate. The Lundgren method for converting the condensed phosphates present to orthophosphate by means of hydrolysis with sulfuric acid was not generally satisfactory because the samples often contained a large amount of particulate matter which caused erratic flow patterns and because a total phosphate rather than a total inorganic phosphate analysis was desired. About 300 samples were analyzed using both digestion procedures. The values were approximately the same for both digestion procedures except when the Lundgren method showed erratic results. The latter was probably due to poor flow patterns caused by particulate matter. The TP data reported herein were obtained using the Kjeldahl digestion method. Levoir-4 detergent was added to the ANSA at the rate of one-half ml/l.

Orthophosphate. The Auto-Analyzer procedure used for the determination of OP employed the reaction of ammonium molybdate in an acid medium to form molybdophosphoric acid that was then reduced to the molybdenum blue complex by reaction with aminonaphtholsulfonic acid reagent. Technicon Corporation (1966) Industrial Method 2.68W was used. One-half ml of Levoir-4 detergent was added to each liter of ANSA to improve the flow pattern.

EXPERIMENTAL DATA AND RESULTS

Introduction

Interpretations of the results of the study to ascertain the amounts of and factors governing pollutional loadings reaching streams from animal production areas are presented in this section. Only sample data and results are presented herein. Full presentation of data, data tables, and figures are given in the Supplemental Appendix available at the Environmental Protection Agency, the Department of Biological and Agricultural Engineering at North Carolina State University, the Water Resources Research Institute of the University of North Carolina (Raleigh), and the North Carolina Department of Water and Air Resources.

Experimental Data

Corresponding hydrological and effluent quality data from all sites are printed by data groups and graphed against time in the Supplemental Appendix. With the exception of NO_3, from sites A, B, and C and COD for the seven swine sites, the following variables are plotted for all sites: rainfall, q_t (reported as depth of flow), T_x, T_n, FC, TC, COD, BOD, TOC, TN, NH_3, NO_3, TP, and OP. No TC or OP data is reported for the dairy, beef, and poultry sites. Conductivity, pH, FS, TS, VS, and COD data for the swine sites are also presented by site and time of collection.

When more than one value of a pollution index was available for a given time because of collection of multiple samples, and/or determination of a particular index more than once on a given sample, average values of the indices are given. Missing index data resulted from either analytical failure or, more commonly, from a decision not to perform the analysis because of insufficient need.

NO_2 and NO_3. The NO_3 values reported herein are the sum of NO_2 and NO_3. NO_2 levels in all samples and NO_3 and NO_2 in the lagoon effluent samples were not significant and, thus, are not reported. The combinations of NO_2-N plus NO_3-N averaged only 0.3 mg/l and never exceeded 0.5 mg/l for more than two hundred samples from the three lagoons. The NO_3-N/NO_2-N ratio for all lagoon samples was about 0.10 and for the stream samples was approximately 10.

The BOD_5 data deserve elaboration because the results of the analyses for the more polluted samples (BOD_5 greater than 60 mg/l) were generally dependent upon the dilution factor, as shown by the following representative results.

% Sample	BOD_5, mg/l
0.75	590
1.00	510
1.50	470

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The BOD variations for strong wastes were discovered early in the study, and a thorough review of procedures failed to account for the variations in terms of procedural errors. Thus, the variations were attributed to characteristics of the BOD test and/or the wastes. Clark (1965) reported that the BOD test was not applicable to swine waste lagoon waters and attributed this to antibiotics, etc., that retarded biodegradation of the wastes. A study of feedlot wastes by Morrison et al (1969) suggested that antibiotics could be present in animal wastes at sufficient levels to cause problems with bio-assays. Studies by Taiganides and White (1969) pointed out limitations and problems associated with applying the BOD test to swine wastes. Scaffer et al (1965) reported the phenomenon of "sliding BOD" for municipal wastes, i.e., lower BOD results with larger amounts of sample. Long-term BOD results for strong wastes were subject to similar variations. The long-term BOD plot in Figure 11 is representative of data obtained from twelve effluent samples analyzed from the three lagoons. The twenty-day BOD values were generally twice the BOD_5 values, and the rate of increase with time was still substantial after twenty days with no indication of onset of a nitrification phase in the classical sense.

A total of 35 samples, 23 of which were lagoon effluent samples, were seeded for BOD analyses. About one-half of the samples were inoculated with a seed developed from lagoon effluent while the rest were inoculated with seed developed from domestic sewage. Standard seed development and inoculation procedures were followed. There were no observed differences between seeded and unseeded samples for either BOD_5 or long-term BOD.

The BOD data reported herein are from analyses in which more than 2 mg/l of oxygen was utilized and more than 1 mg/l of oxygen remained after incubation. When variations occurred, the BOD value obtained from the less dilute samples was taken as the correct value except when two or more values for other dilutions were in close agreement but different from this value. In the latter instance, the BOD in best agreement with the less dilute sample was chosen. This procedure produced results consistent with findings for other indices. An intensive review of alternative methods showed no improvement over this method of selection.

Simple Statistics and Regression Analyses

The data collected during the study were subjected to standard computerized statistical analysis in order to determine the applicability of the procedures used in the study, to evaluate the suitability of the pollution indices, and to develop relationships for estimating the effects of animal production units on water quality under similar management conditions. Simple regression analyses revealed relatively high correlations between many of the pollution indices. These correlations suggest that substantial savings can be made in stream quality surveys by limiting the analyses to a few key indices with the remainder being estimated.

Means (M), standard deviations (s), and linear correlation coefficients (r) for the data are presented in Tables 27-80 of the Supplemental Appendix. The number of values, No., used in each analysis is also

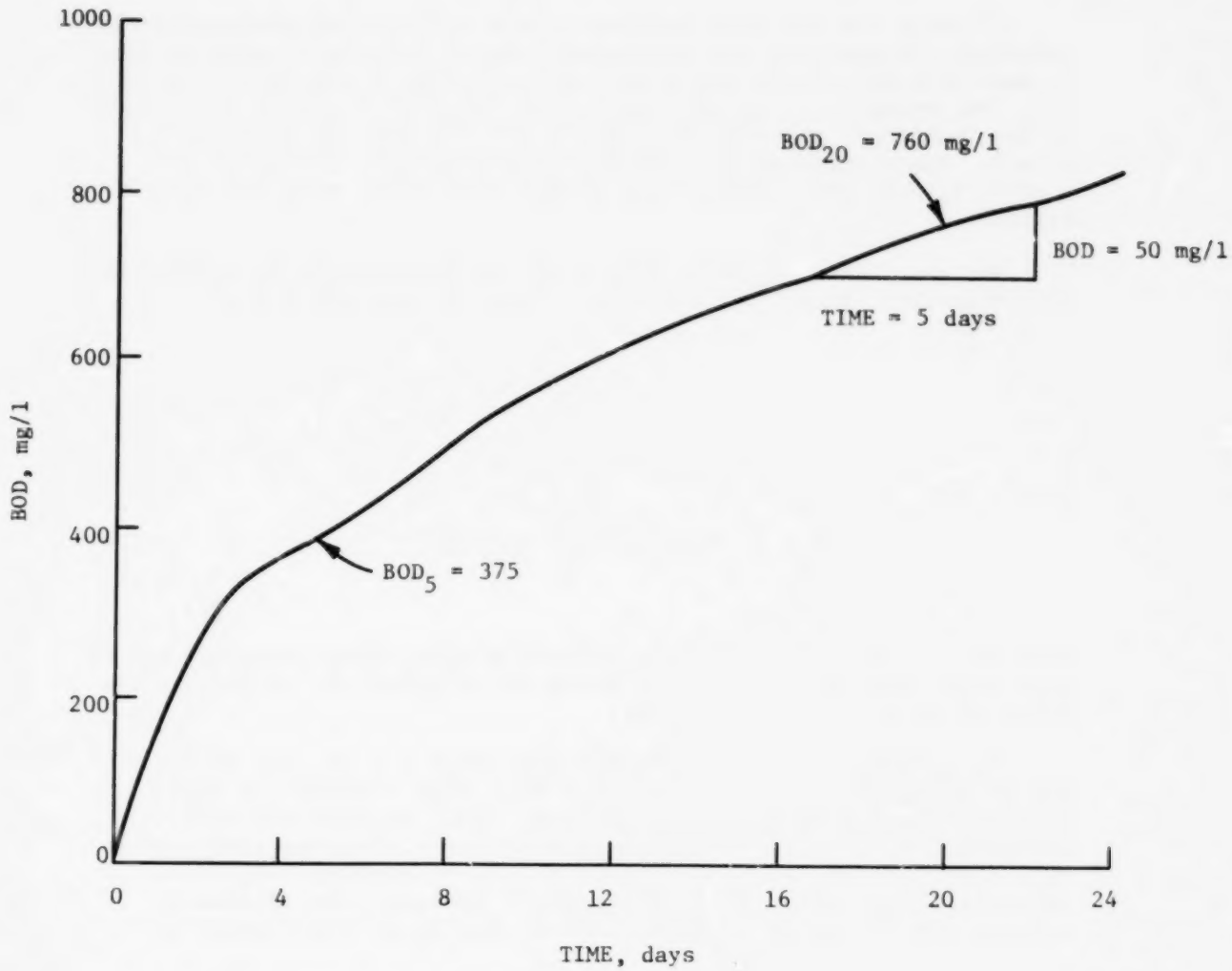

Figure 11. Representative long-term lagoon effluent BOD

recorded. The simple statistics reported in Tables 41, 54, 67 and 80 were obtained using all values of data for the given data group; i.e., FC for data group A in Table 41 is the mean for all FC values from site A. The simple statistics reported in the remaining tables were obtained using paired observations. The means for some indices are larger than the means of related indices in apparent contradiction to what might normally be expected; e.g., $\overline{FC}$ larger than $\overline{TC}$. This is due to the fact that the TC and FC data are not necessarily mutually paired when paired with other indices.

Although the data were grouped to make analyses and presentation as meaningful as possible, any interpretations of the results reported must be made with due caution and a full understanding on the particular data bit. For example, q_t for data group E in Table 41 is simply the average of the individual q_t values recorded at the 176 times of sampling at site E. Since sampling was commonly associated with rainfall-runoff events, q_t does not represent the average flow rate during the study period.

The data obtained during this study are random pairs of observations from bivariate normal distributions. Thus, the regression equation of y on x is:

$$y = \overline{y} + r \frac{s_y}{s_x} (x - \overline{x})$$

Similarly,

$$x = \overline{x} + r \frac{s_x}{s_y} (y - \overline{y})$$

When the correlation between two indices is high, these equations may be used under comparable conditions to obtain equations for estimating the value of one indice given another.

For example, r for FC vs TC for data group E, i.e., all paired FC and TC observations from site E, is 0.957. High r values are also reported for sub-groups of data group E. Thus, the need for both determinations in similar studies is nonexistent since one index can be determined from the other with about 92 percent accuracy. If FC were selected as the indice to be determined by analyses, the prediction equation for TC from land disposal sites similar to site E would be:

$$TC = 39{,}540 + 0.957 \frac{167{,}580}{77{,}081} (FC - 19{,}050)$$

$$= 2.1\ FC + 100$$

The TOC test proved particularly promising for use in developing relationships to evaluate other indices because it is simple, rapid, and

reliable and correlates well with the other indices. Certain correlations between TOC and the other indices are summarized in Table 1. These are all significant at the 0.01 level except for FC from sites X, J and ABC.

Table 1. Correlation coefficients, r, for TOC with other pollution indices.

Site	r			
	FC	BOD_5	TN	TP
Control, F	.406	.734	.943	.883
Land Disposal				
E(swine)	.437	.966	.875	.899
K(swine)	.794	.920	.665	.425
P(poultry)	.491	.610	.926	.730
X(poultry)	.050	.972	---	---
Z(beef)	.895	.724	.955	.620
Lagoons, ABC	.037	.666	.637	.473
Direct Discharge				
D(swine)	.655	.955	.676	.735
H(dairy)	.838	.970	.708	.714
J(dairy)	.207	.893	.583	.393

The following simple regression equations with TOC as the independent variable and BOD_5 as the dependent variable demonstrate the types of potentially useful relationships which can be developed for the assessment of pollution under applicable conditions:

Land runoff from:

	Site
Swine wastes	E
$BOD_5 = 0.79\ TOC - 2.5$	
Dairy wastes	H
$BOD_5 = 0.66\ TOC - 2.0$	
Poultry wastes	P & X
$BOD_5 = 0.35\ TOC$	

Multiple Regression Analyses for Data from the Swine Sites

Results of multiple regression analyses of the swine waste data with FC, TC, BOD_5, TOC, TN, NH_3, NO_3, TP, and OP each as the dependent variable

and T_n, H, and q_o as the independent variables are presented in Appendix F of the Supplemental Appendix. The coefficients of determination, R^2, and the number of data points, No., are also presented for each analysis. These analyses failed to produce equations of general applicability for predicting stream pollution. Low R^2 values were obtained for many sets of data and inconsistencies in the equations developed for similar sets of data were common.

The inconsistencies in results between data groups are illustrated by the BOD_5 regression equation for data collected from site E during March 1-7, 1969,

$$BOD_5 = 28.7 - 1.07\ T_n + 124.9\ q_o$$

The equation has a significant R^2 value of 0.792 while that for June 2-19, 1969,

$$BOD_5 = -34.6 + 0.65\ T_n + 30.5\ q_o$$

has a significant R^2 value of 0.734. Although the R^2 values suggest that these equations are sufficiently accurate for general use, under similar conditions the inconsistency of the equations, exemplified by the four-fold difference in the q_o regression coefficients, limit their usefulness.

Failure to obtain general predictive equations was likely caused by variations in vegetative cover, antecedent moisture, topography, soil types, time of waste application with respect to rainfall and other similar factors not considered in developing the equations. A recent report of cooperative Watershed Research in Western North Carolina by the Tennessee Valley Authority and Department of Soil Science at North Carolina State University (Anon., 1970) contributes to an understanding of the difficulties encountered in developing prediction equations. In their extensive, long-term study the investigators found the identical or truly paired small watershed concept to be an illusion. As the size of an area diminishes, the effect of relatively minute differences in soil characteristics upon hydrology is exaggerated and assumes disproportionate importance. No usable representative measures of hydrologic response were identified. Instead, many factors including antecedent moisture, cultivation, climate, etc. were found to cause variations in soil properties and hydrologic response. While differences in level of stream-flow response to four agricultural covers were noted, the relationship between cover and level of stream-flow response was found to vary with soil types. Where deep, permeable soils were present, the cover was found to be relatively less important. Also, partial watershed area runoff accounted for the non-linear response of a watershed to rainfall. Soil surface crusting and soil saturation markedly increased the stream-flow response. The key to projecting hydrologic information from very small areas to larger areas, they reported, lies in accounting for variations in moisture-storage capacities of soils in respective watersheds.

Nevertheless, the high R^2 values for some of the equations obtained for the land runoff data groups (sites E, F, and K) show promise that equations of general applicability for predicting stream pollution from land runoff sites might be developed with a more detailed and longer term study. Estimating equations for BOD_5 and TOC from the control watershed (F) are examples. Normative values for these indices ranged between 0-2 and 5-10 mg/l, respectively, in the absence of rainfall. The regression equation from data collected between March 18-25, 1969,

$$BOD_5 = 2.8 - (0.035)\ T_n + 2.2\ (q_o)$$

has an R^2 value of 0.604 and produces a BOD_5 estimate of 1.1 mg/l at a minimum daily temperature of 50°F and a runoff flow rate of zero. The TOC regression equation for tne same data

$$TOC = 5.6 + (0.024)\ T_n + (13.9)\ q_o$$

has an R^2 value of 0.498 and estimates a TOC of 6.8 mg/l under the same conditions. At a runoff flow rate of 1 cfs and T_n of 50°F, the equations estimate a BOD_5 of 3.3 mg/l and a TOC of 20.7 mg/l. These values are fairly consistent with normative values observed during runoff periods.

In other multiple regression analyses, q_o was replaced by other flow data; e.g., q_t, q_b, and q_t to various powers, and T_n was replaced by T_x. These attempts did not provide an improvement in the ability to predict the pollution indices and, thus, the results are not reported.

Selected multiple (and step-wise) regression analyses were performed using BOD_5, TOC, etc. as independent variables. Examples of these analyses are reported in Appendix G of the Supplemental Appendix. Although these analyses generally gave considerable improvement in the resulting regression equations for the land runoff sites, their use requires that a pollution indice, e.g., TOC, for the wastewater be known. For example, the BOD_5 regression equation for data group E with T_n, H, and q_o as the independent variables

$$BOD_5 = -1.3 - 0.517\ T_n + 0.012\ H + 34.1\ q_o$$

has an R^2 value of only 0.435 while the BOD_5 equation with TOC added as an independent variable

$$BOD_5 = 2.1 + 0.9\ TOC - 0.05\ T_n - 0.004\ H - 6.4\ q_o$$

has an R^2 value of 0.946. The equation with only TOC and q_o as the independent variables

$$BOD_5 = 3.3 + 1.08\ TOC + 10.1\ q_o$$

has an R^2 value of 0.947. These equations indicate that T_n and H were not important in determining the BOD_5 in the stream under tne conditions and within the time span experienced in this study. They also substantiate

the high correlations between TOC and other pollution parameters developed in the simple regression analyses.

The step-wise equations for the lagoon effluent data still showed low R^2 values and inconsistency. This reflects the low correlations between variables in these data. Although a number of the equations for the direct discharge stream show high R^2 values, they are still unsatisfactory as prediction equations in light of the changes which occurred in pollution indices with time and with the intensity of pollution which are not accounted for by the equations.

Swine Waste Studies

Lagoon Influent Studies

Values of the pollution indices obtained from samples of the influent (diluted fresh swine waste) to the lagoons were quite variable. Based on only 10 samples, typical indice values for the influent to lagoon A were:

TC	20×10^6 colonies/100 ml
FC	6×10^6 colonies/100 ml
FS	1.5×10^6 colonies/100 ml
BOD_5	725 mg/l
TOC	680 mg/l
COD	1400 mg/l
TS	1700 mg/l
VS	1000 mg/l
TN-N	200 mg/l
NH_3-N	100 mg/l
NO_3-N	1 mg/l
TP-PO_4	85 mg/l
OP-PO_4	75 mg/l

Higher values were common for influent samples to the other lagoons due to lesser amounts of dilution. Not enough influent data were obtained to accurately delineate the amount of waste contributed to the lagoons per hog per day. However, when the number of hogs and volume of wash water were considered, the 10 samples collected at site A indicated that the daily production per hog of FC, BOD_5, COD, TS, TN, and TP was within the range reported by others for fresh swine waste; e.g., Muehling (1969).

The influent FS levels were much lower than expected, and the FC/FS ratio was normally four for all lagoon influents. Thirty subsequent samples of the lagoon influents verified this ratio. According to Geildrich (1966) the expected ratio for waters containing animal wastes is less than 0.5. The higher FC/FS ratio reported herein may have been caused by the KF medium used in the FS test. The medium was supposed to inhibit growth of bacteria other than FS and to produce colonies light to dark pink in color. However, pale yellow colonies were normally present after incubation. Only the pink colonies were counted as FS.

Lagoon Effluent Studies

The three lagoons investigated in this study had surface outflows that were measured and analyzed to determine the amount of water pollution resulting from anaerobic lagooning operations. Any water pollution via subsurface discharge into the streams from the lagoons was not measured. This was judged minimal because the lagoons were located in clay soils that had low hydraulic conductivities and because of the sealing properties of lagoon liquor. In fact, subsurface flow into lagoon A was more of a possibility as discussed later.

Examples of effluent quality data and corresponding hydrological data for lagoon A are presented graphically in Figures 12-18. The large variations encountered in most of the data from the lagoons emphasize the need for caution when only occasional samples are used to characterize the water pollution potential from this source.

The number of unit hogs, H, at each site were determined by dividing the total weight of swine in pounds by 100 lbs. H remained nearly constant at each lagoon during the study periods. The slight variations (± 10%) that did occur were judged insignificant for the study. The number of unit hogs for sites A, B, and C were 300, 100, and 90, respectively.

Factors such as the amount of wash water used per animal markedly affected the concentrations of pollutants between sites. Thus, the effect of H on the pollutional yields from the lagoons presented herein was evaluated in terms of the amounts of pollutants discharged in the effluents per H as opposed to relating the variations in concentrations of pollutants to H.

Hydrological Data. Rainfall in the area of the lagoons averages 50 in./yr. and evaporation for small lakes in the geographical location is normally 35 in./yr. Evaporation from lagoons was not investigated, but was probably less than that from small lakes because of surface solids and scums. Even if evaporation from lagoons were equal to that from small ponds, a lagoon would produce an effluent because of the 15 surface inches per year of rainfall in excess of evaporation, the waste volume, the surface runoff from surrounding areas, and the wash water. Subsurface inflow and/or outflow would also be considered in a water balance. The contribution due to waste volume would generally be insignificant in a water balance. The production of fresh swine wastes is about 1 gal/day/H.

As exemplified in Figure 12, rainfall produced hydrographs of surface effluent flow from the lagoons similar to hydrographs characteristic of a small watershed, i.e., a rapid increase in flow rate followed by a prolonged die off to base flow. Wash-down events were not discernible from effluent flow records at site A. Small peaks in the flow rate were identified at site C when wastes were added to the lagoon. Occasional increases in the rate of effluent discharge were observed at site B following wash-down operations. Some of the variations in effluent flow rates from the lagoons were caused by floating debris that restricted the flow through the overflow pipes. The variations in q_t at site A during November 20-23, 1968, were accompanied by an apparent inversion of the lagoon liquor caused by a temperature change.

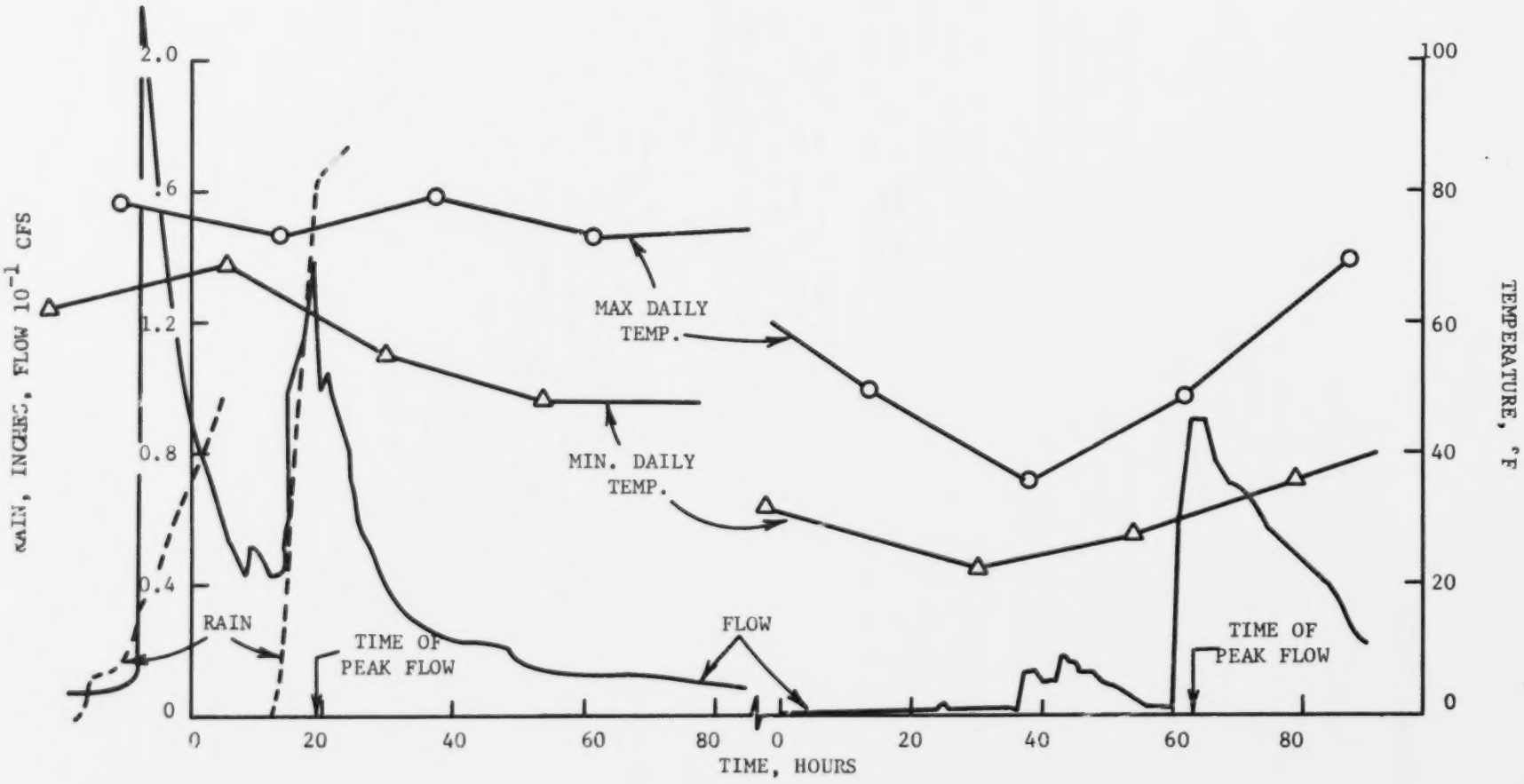

Figure 12. Hydrological Data, Site A, Oct. 19-21 and Nov. 20-23, 1968.

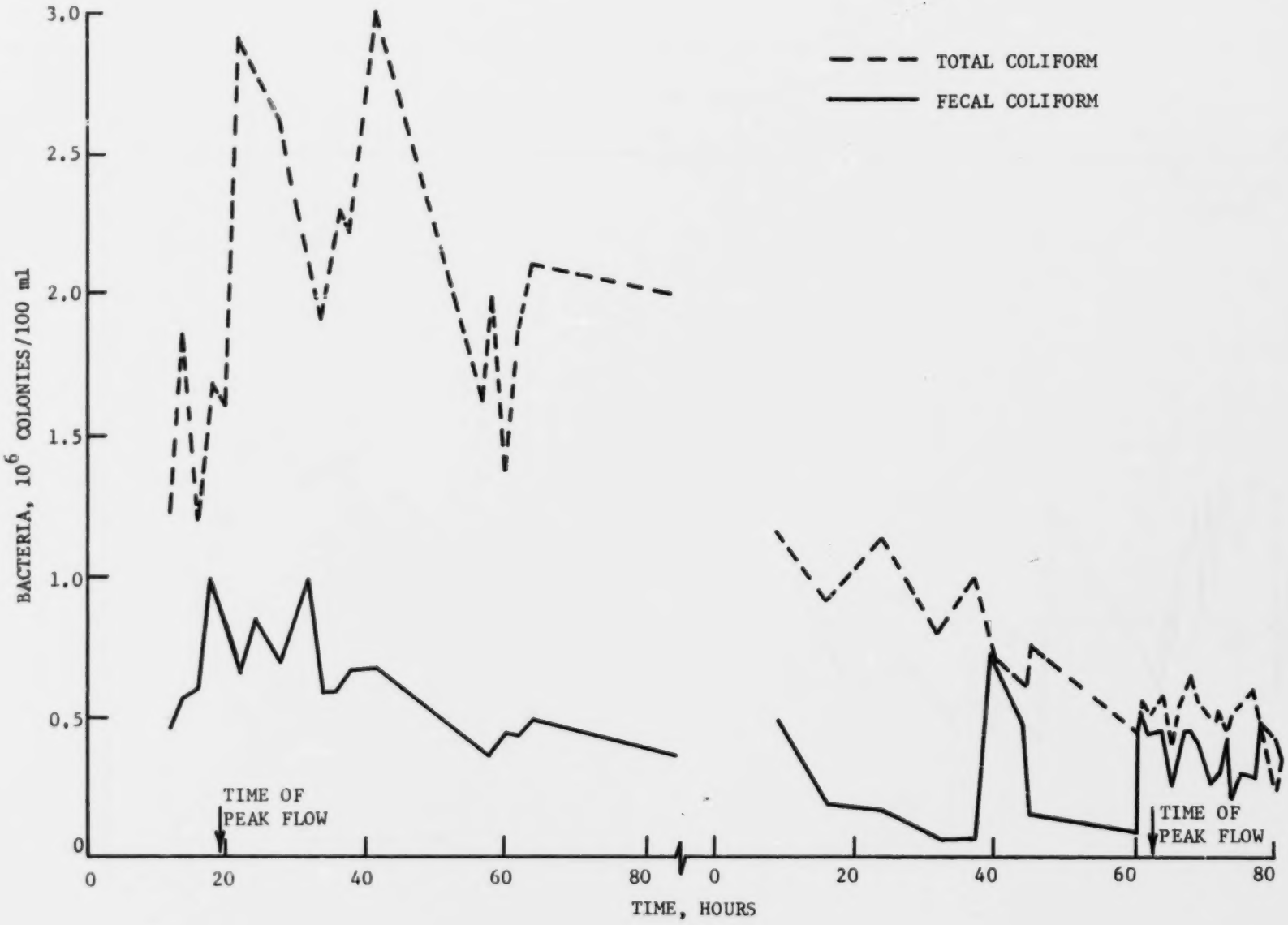

Figure 13. Bacteria Counts, Site A, Oct. 19-21 and Nov. 20-23, 1968.

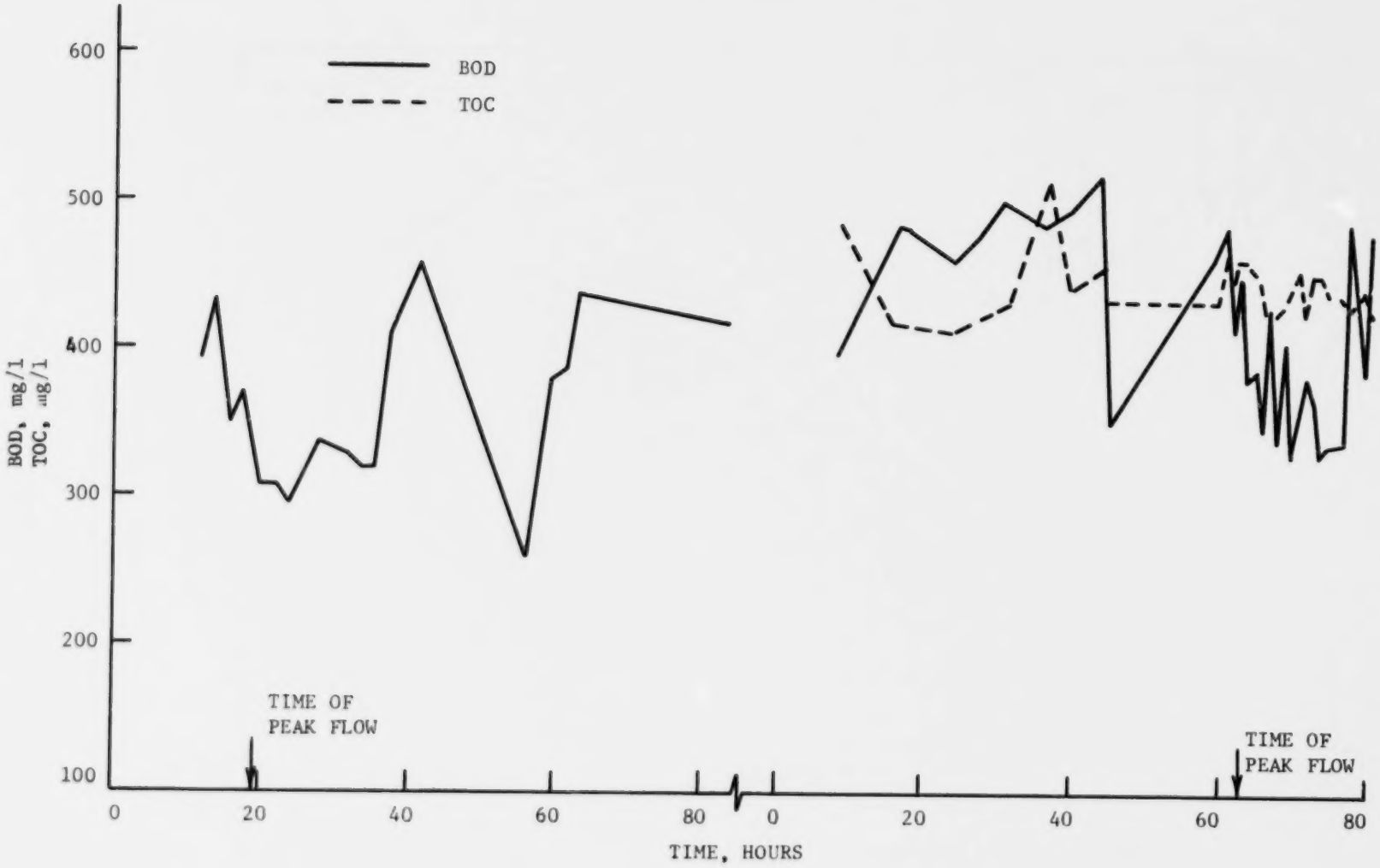

Figure 14. BOD_5 and TOC, Site A, Oct. 19-21 and Nov. 20-23, 1968.

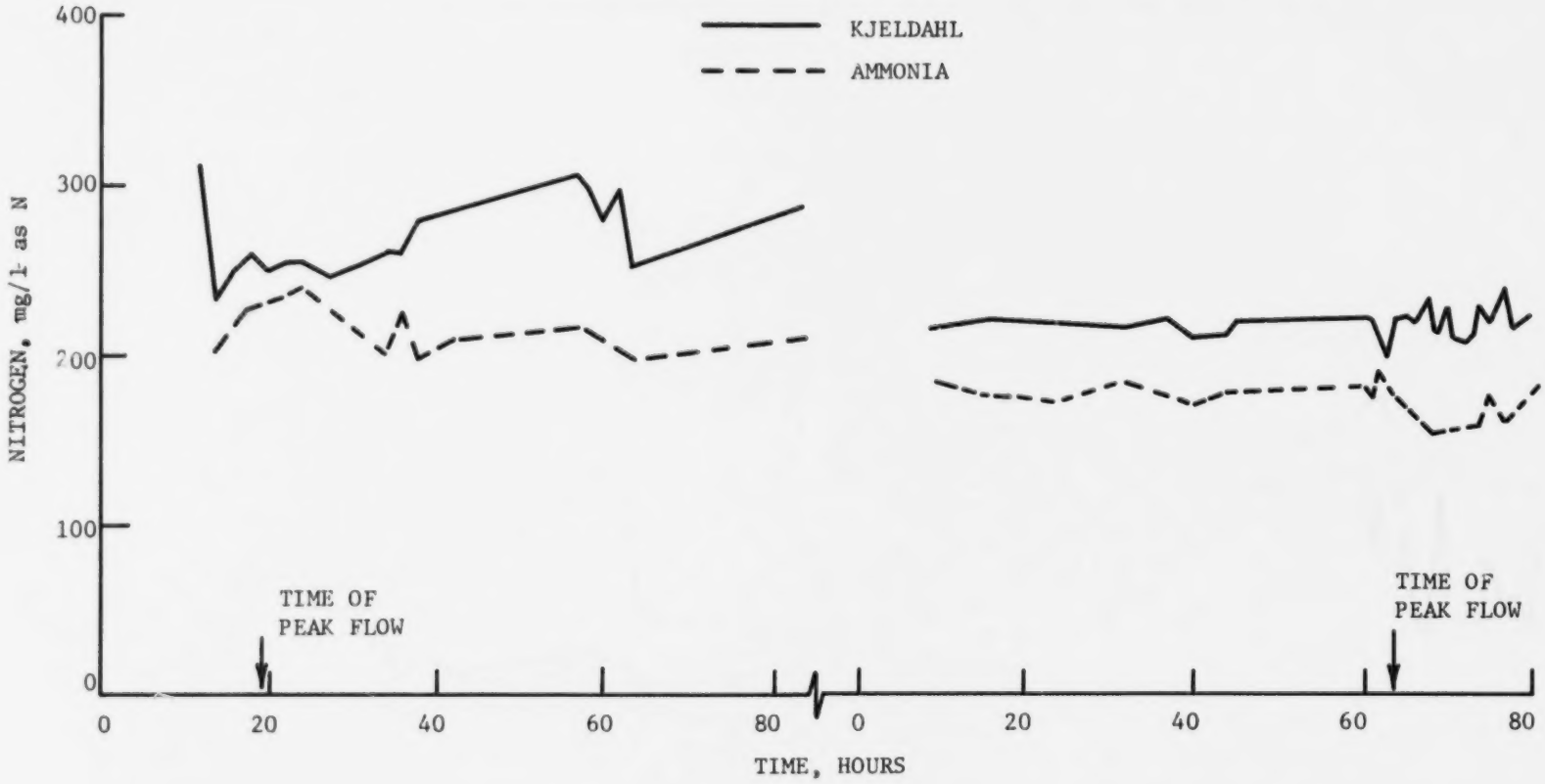

Figure 15. Kjeldahl and Ammonia Nitrogen, Site A, Oct. 19-21 and Nov. 20-23, 1968.

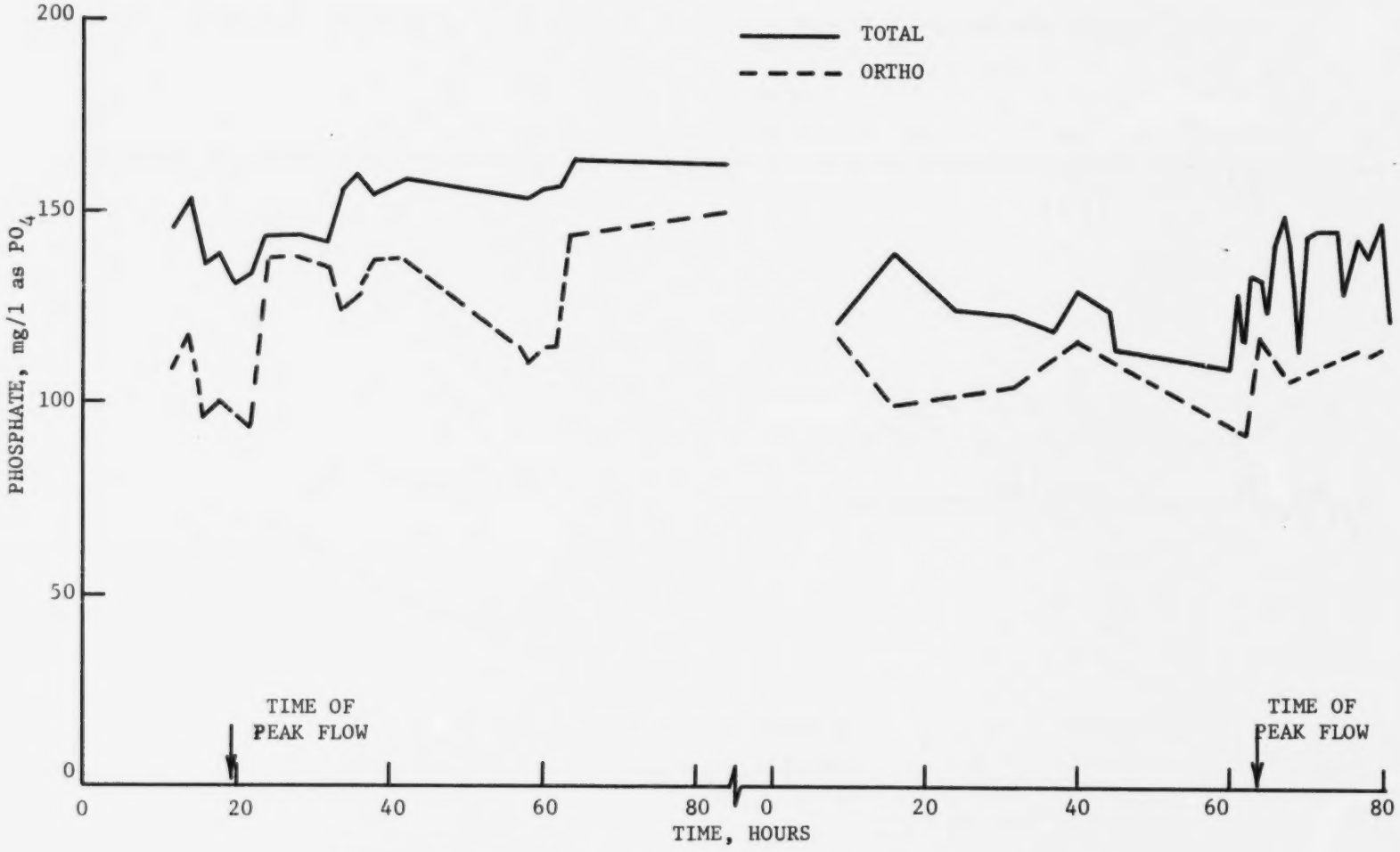

Figure 16. Phosphate, Site A, Oct. 19-21 and Nov. 20-23, 1968.

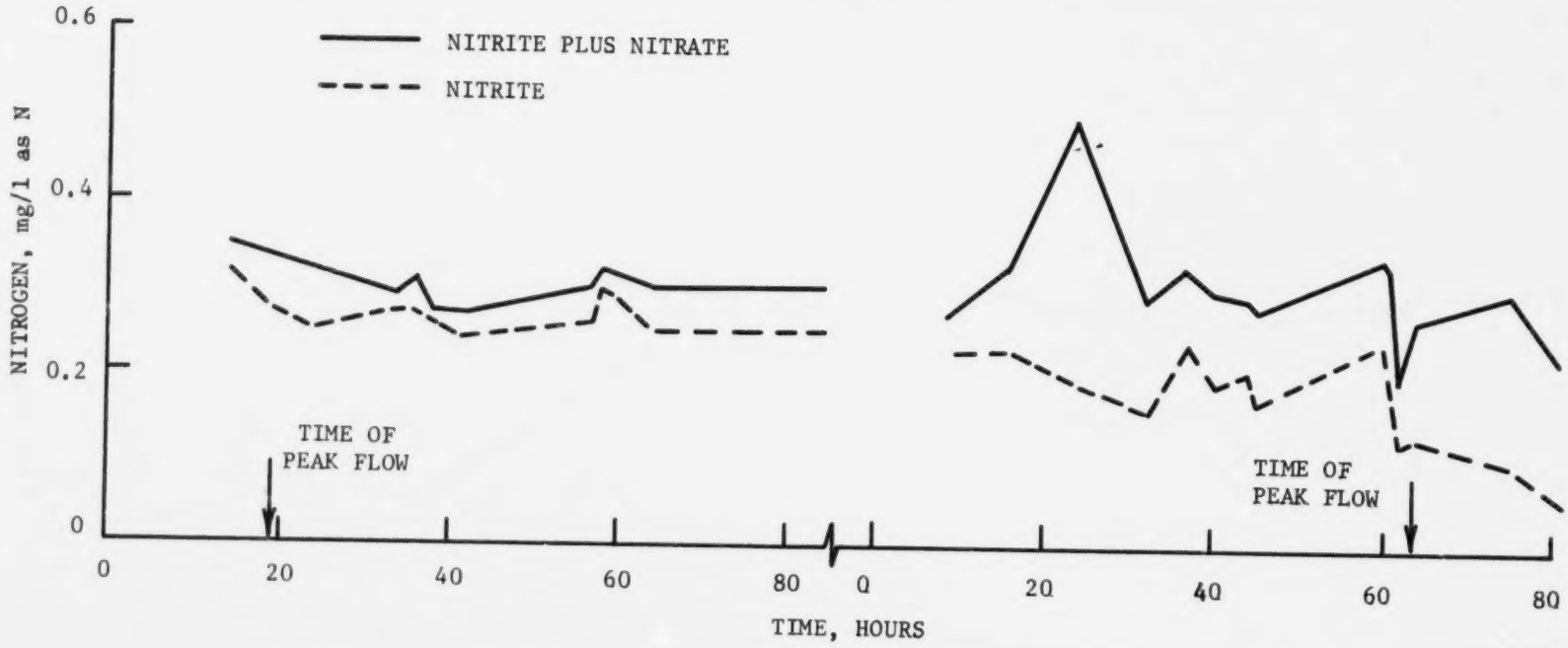

Figure 17. Nitrite and Nitrate Nitrogen, Site A, Oct. 19-21 and Nov. 20-23, 1968.

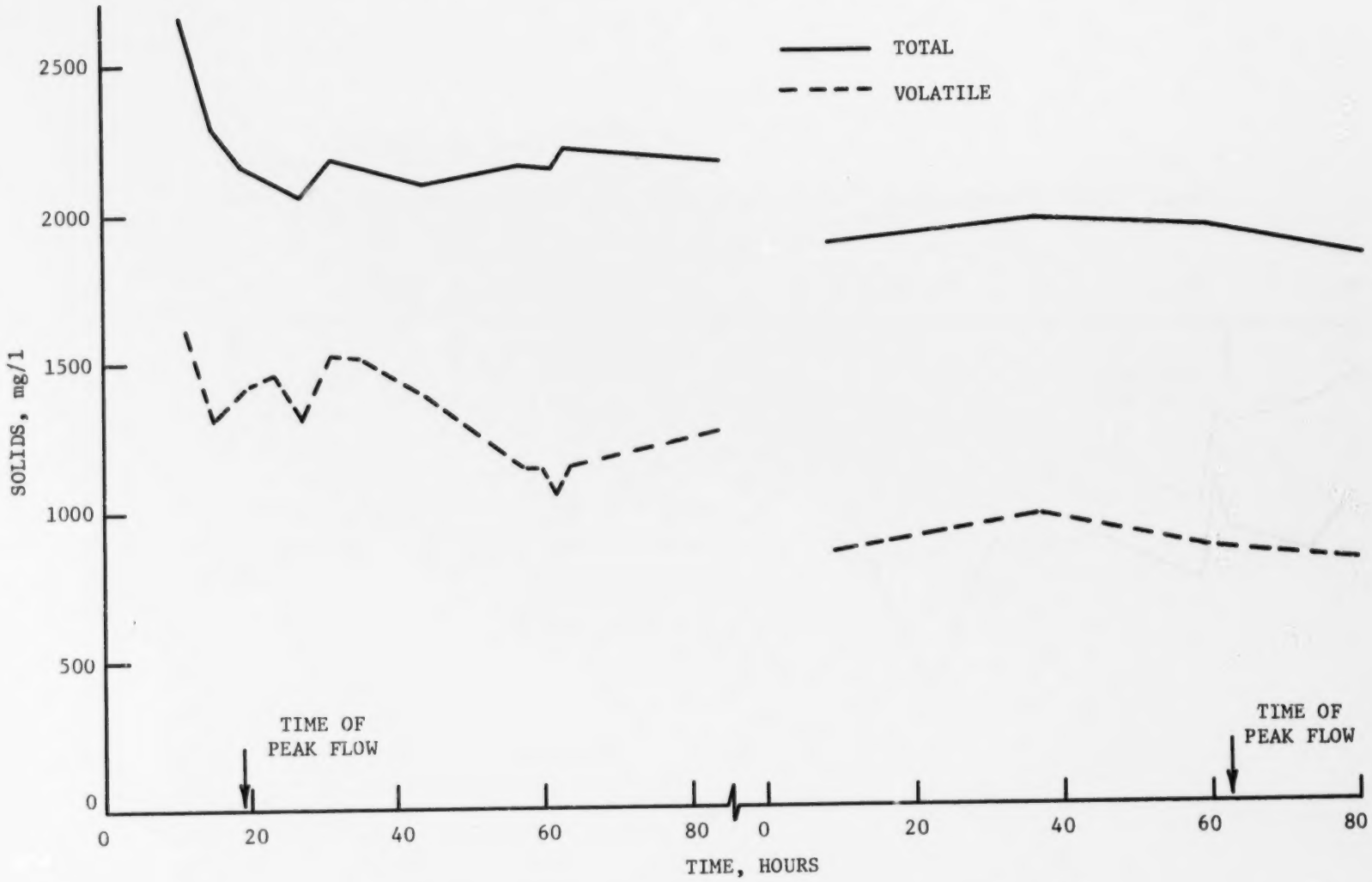

Figure 18. Solids, Site A, Oct. 19-21 and Nov. 20-23, 1968.

Neither q_t, q_b, nor q_o correlated well with the pollution indices for most lagoon effluent data groups. The poor correlations might be explained by noting that the lagoon volumes provided ample opportunity for the lagoon liquor to reach uniformity with respect to pollutional content and any variation in flow simply removed more or less liquor that had a rather constant waste content. Thus, other factors were more important in governing the pollution indice values than was flow rate.

The largest surface effluent discharge rates occurred during late fall to early summer when rainfall was greatest and evaporation least. The effluent discharge results of Table 2 were obtained by assuming that the average effluent flow rates which occurred at time of sampling; i.e., $\overline{q}_t$ represents the average flow rate ($\overline{q}$).

Table 2. Rates of effluent flows from the lagoons

GROUP (Site)	q_t, cfs			$\overline{q}$			
	max	mean	min	$\frac{\text{ac-ft}}{\text{yr}}$	ft^3/yr	gal/day	gal/day/H
A	.285	.027	.001	19.2	840,000	17,250	58
B	.057	.002	0	1.6	68,000	1,400	14
C	.052	.002	0	1.2	50,000	1,050	12

The large yields from lagoon A suggest subsurface flow into the lagoon. The measured rate of wash-water usage in the operation was 15 gal/day/H. An estimated additional 15 gal/day/H was added to the lagoon by leaky water valves and swine wastes. A difference in rainfall and evaporation of 15 in./yr. represents a net yield of 4.5 gal/day/H from the 50,000 ft^2 lagoon. An assumed yield of 30 in./yr. of surface runoff entering the lagoon from the surrounding 20,000 ft^2 contributed another 3.5 gal/day/H. A large portion of the 20 gal/day/H not accounted for must have come from subsurface sources. This is plausable because the lagoon was the headwater of a continuously flowing stream.

The effluent yields from lagoons B and C were in the range expected. Wash-water usage was 10 gal/day/H and waste volume was estimated to be 1 gal/day/H. The 15 in./yr. difference in rainfall and evaporation accounted for an additional 1.8 gal/day/H. Surface runoff at 30 in./yr. accounted for 1.7 gal/day/H at site B and 0.8 gal/day/H at site C for totals of 14.5 and 13.6 gal/day/H, respective.y

Bacteria Indices. Bacteria counts in the effluents from the three lagoons were generally highest for lagoon B and lowest for lagoon C. The trend shown in Figure 13 during the October 19-21 period for TC and FC counts to increase and decrease in direct relation to the effluent hydrograph was not verified by other data. In fact, the correlation coefficients indicate almost no general linear relationships existed between the bacteria indices and the other pollution indices or hydrological factors. However, the bacteria indices were well correlated with

each other at sites A and C. Usually, TC and FC were poorly correlated at site B.

Bacteria counts were lower during the late spring and summer period than during the fall and winter months. This is reflected by the negative correlation coefficients for FC and TC with T_x and T_n for data obtained from sites B and C. However, the failure of such a general correlation between bacteria counts and temperature for data from site A suggests that temperature was not the sole factor involved in this phenomenon.

The lower than normal TC values and TC/FC ratios obtained during November 21-23 at site A (Figure 13) and on November 23, 1968, at site B may have been caused by higher than normal concentrations of antibiotics and/or other toxic substances in the lagoon liquor if fecal organisms are assumed to be more tolerant to these substances than are total coliform organisms. Erratic variations in BOD_5 levels also occurred at lagoon A during this period. This suggests that an inversion of lagoon liquor caused by the drastic drop in temperature occurred. This supposed inversion of lagoon liquor could have released toxic materials from the lagoon bottom. Clark (19) reported a similar bacteria ratio disturbance in swine lagoon waters receiving wastes from hogs that had been fed unusually large amounts of antibiotics plus sulfur drugs.

Results of calculations of the bacteria yields in the lagoon effluents are shown in Table 3. The value for FC/day/H for data group A was obtained by multiplying the mean of all FC measurements made on the effluent samples from lagoon A by $\overline{q}$ for data group A from Table 2. The value of TC/FC for data group A was obtained from all paired TC and FC measurements made on the samples from lagoon A. The other results were obtained in a similar manner. The average yields or FC were only 10 percent at site A, 6 percent at site B, and 1 percent at site C of the average production rates for fresh swine wastes, 8.9×10^9 col/day/H, reported by Gieldreich (1966).

Table 3. Bacteria in effluents from the lagoons

GROUP (Site)	FC				TC				TC/FC
	10^6 col/100 ml			10^6 col/day/H	10^6 col/100 ml			10^6 col/day/H	
	max	mean	min		max	mean	min		
A	1.05	.42	.03	900	3.00	1.22	.22	2,600	2.9
B	2.10	1.04	.06	490	4.10	2.06	.30	1,000	2.0
C	.97	.17	.01	90	1.45	.38	.01	200	2.2

BOD_5 and TOC. The concentrations of BOD_5 in the lagoon effluents and the total amount of BOD_5 discharged to streams were usually greater during the colder months than during the warmer periods. This may have been partially due to the more favorable temperature for biological activity

during the warmer periods and thus more biological treatment of wastes. However, the correlation coefficients between BOD_5 and temperature were generally too low and inconsistent to attribute this phenomenon solely to this hypothesis.

TOC values for the lagoon effluent were quite reproducible and free of noticeable errors. The test was free of the erratic variations common to the BOD test. The data collected during the study showed that the TOC values followed the same general pattern of increasing during the colder periods and decreasing during the warmer months as did the BOD_5. Variations in TOC with season were generally less than those for BOD_5.

During the early part of the study, BOD_5 values generally exceeded TOC values. After February 1969 TOC values generally exceeded BOD_5 values for site B. This change was delayed until April 1969 at sites A and C. A reversal (TOC greater than BOD_5) did occur at site A during the period of November 21-23, 1968 (Figure 14). As discussed previously, an inversion of the lagoon liquor probably occurred during this time due to a drop in temperature. If toxic substances were released from the lagoon bottom, these could have retarded the biochemical oxygen demand, reducing the BOD_5/TOC ratio.

The reversal in the BOD_5/TOC ratio during the spring for all three lagoons might have been caused by an increase in toxic materials in the lagoon waters during the warmer periods, but no justification of this hypothesis is available. Another possible explanation of the reversal is that the wastes were more highly oxidized during the warmer period. Since the decrease in BOD_5 from winter to spring was more drastic than that for the TOC, this explanation seems more plausible.

TOC and BOD_5 values in the effluents from the three lagoons were generally highest for lagoon C and lowest for lagoon B. This was just the opposite of the bacteria values which were highest for lagoon B and lowest for lagoon C.

Neither BOD_5 nor TOC values for the lagoon effluent correlated well with the other pollution indices. TOC was only slightly better than BOD_5 in this respect.

Results of calculations of the BOD_5 and TOC yields in the lagoon effluents are shown in Table 4. The value for BOD_5/day/H for data group A was obtained by multiplying the mean of all BOD_5 measurements made on the effluent samples from lagoon A by $\bar{q}$ for data group A from Table 2. The value of BOD_5/TOC for data group A was obtained from all paired BOD_5 and TOC measurements made on the samples from lagoon A. The other results were obtained in a similar manner. Although large differences in BOD_5 and TOC occurred between individual samples, the results are similar in terms of lb/day/H. Thus, in the long run the same conclusions concerning the applicability of lagoons for swine waste treatment can be drawn from either the BOD_5 or the TOC.

Table 4. BOD_5 and TOC in effluents from the lagoons

GROUP (Site)	BOD_5				TOC				BOD_5/TOC
	mg/l			lb/day/H	mg/l			lb/day/H	
	max	mean	min		max	mean	min		
A	610	390	90	.181	510	360	165	.170	1.1
B	600	270	80	.028	550	340	200	.035	0.8
C	1015	610	215	.071	815	470	355	.055	1.4

The BOD_5 in lbs/day/H in the effluents were 59 percent at site A, 9 percent at site B, and 22 percent at site C of the average production rates for fresh swine wastes, 0.32 lb/day/H, reported by Meuhling (1969). The apparent differences in treatment efficiencies between lagoons may be partially attributed to the differences in feeding practices. As mentioned earlier, a particularly high rate of copper sulphate was fed at site A and cooked garbage was a major part of the feed. The operations at sites B and C followed recommended feeding practices.

A more plausible explanation is that BOD_5 and TOC yields were related to the time of waste retention. The volumes of lagoons A, B, and C were about 250, 120, and 160 $10^3 ft^3$ while the effluent flow rates were 840, 68, and 50 $10^3 ft^3$/yr, respectively. The volume displacement times obtained by dividing the effluent flow rates into the volumes were 0.3, 1.8, and 3.2 yrs, respectively. These figures must be interpreted in a relative rather than absolute sense, however, in view of the flow-through measurements which demonstrated that a portion of liquid swine wastes flowed through the lagoons in a few hours with the major part being retained for longer periods.

The differences in age of the lagoons may have been an added factor in governing the BOD_5 and TOC yields. The lagoons had been used 6, 3, and 2 years, respectively, before the study began. Solids had built up above the surface at the inlet of lagoon A. No solids were observed from the banks of the other two lagoons.

Differences in capacity/H may have been another factor. The values were about 830, 1200, and 1800 ft^3/H while surface areas were about 170, 200, and 220 ft^2/H, respectively.

Any one of the above factors may have influenced the BOD_5 and TOC yields. The most plausible factor is retention time because it showed sufficient variation to account for the large variation in the indices, and it is related to the other factors involved.

Nitrogen. Total (Kjeldahl) nitrogen concentrations doubled at sites B and C from the fall of 1968 to the spring of 1969. They were highest in early May with values of 280 and 560 mg/l, respectively. During the same period, TN concentrations decreased at site A and continued to decrease until the end of the study, summer of 1969. The poor

correlations between TN and q_t suggest the changes in concentrations were not caused by variations in flow and/or dilution by rain water.

TN and NH_3 were linearly related to each other. However, the poor coorelations for some data groups preclude recommending substitution of one test for the other. Ammonia nitrogen levels followed the trends of TN and accounted for 60-100 percent of the TN. The NH_3 averaged 80 percent of the TN for all lagoon effluent samples. Correlations between TN and NH_3 and the other data were not consistent and were often nonsignificant.

Results of calculations of the nitrogen yields in the lagoon effluents are shown in Table 5. The value for N/day H for data group A was obtained by multiplying the mean of all TN measurements made on the effluent samples from lagoon A by $\bar{q}$ for data group A from Table 2. The value of TN/NH_3-N for data group A was obtained from all paired TN and NH_3 measurements made on the samples from lagoon A. The other results were obtained in a similar manner. At a land application rate of 1/10 ft of lagoon liquor the nitrogen application rate would be 66, 46, and 78 lb/acre from lagoons A, B, and C, respectively.

Table 5. Nitrogen in effluents from the lagoons

GROUP (Site)	N					TN/NH_3-N
	mg/l			lb/ac-ft	lb/day/H	
	max	mean	min			
A	330	244	120	660	.115	1.2
B	345	168	88	450	.018	1.4
C	560	287	205	780	.033	1.2

The results from sites B and C suggest that some nitrogen may be removed by lagoons. This was probably associated with solids removal and/or retention.

Phosphate. Total phosphate concentrations in the effluents were rather uniform at each site throughout the study periods, but variations between samples collected at close time intervals were greater than expected. There was a slight decrease in TP content at each site during early spring. This was followed by a slightly larger increase at sites B and C while at site A the TP level returned to its previous value.

Generally, TP and OP were linearly correlated. OP averaged 83 percent of the TP for all lagoon effluent samples. Correlations between TP and OP and the other data were often non-significant.

Results of calculations of phosphate yields in the lagoon effluents are shown in Table 6. The value for PO_4/day/H for data group A was obtained by multiplying the mean of all TP measurements made on the effluent samples from lagoon A by $\overline{q}$ for data group A from Table 2. The value for TP/OP for data group A was obtained from all paired TP and OP measurements made on the samples from lagoon A. The other results were obtained in a similar manner. At a land application rate of 1/10 ft of lagoon liquor the P_2O_5 application rate would be 29, 22, and 24 lb/acre from lagoons A, B, and C, respectively.

Table 6. Phosphate in effluents from the lagoons

GROUP (Site)	PO_4					TP/OP
	mg/l			lb/ac-ft	lb/day/H	
	max	mean	min			
A	200	142	74	390	.069	1.2
B	214	112	78	300	.012	1.2
C	160	116	80	320	.013	1.2

Discussion. Although large variations in pollution indice values were encountered between samples and lagoons and with time, sufficient data were collected to assure that the results are representative of normal contributions of anaerobic swine waste lagoons in the Piedmont area of North Carolina. While the study lagoons provided more capacity per animal than USDA and other recommended standards, the lagoon effluents clearly exceeded raw domestic sewage in strength.

The study lagoons appeared to function mainly as traps, i.e., settling and retention basins, and provide only a limited amount of treatment beyond that experienced through sedimentation. Lagoons B and C functioned more efficiently with regard to amounts of pollutants removed but not in terms of the strength of the effluents. At site A the calculated decreases in bacteria and organic pollution discharged compared to the estimated inputs based on characterization of fresh wastes must be viewed in light of the corresponding increases in phosphorus and nitrogen.

Such management practices as wash-down were of major importance in controlling the amount of wastes reaching streams. The waste load to receiving streams increased with volume of effluent and decreased with longer periods of waste retention.

Direct Discharge Study

The direct discharge site was studied only a short period of time because the practice of directly discharging wastes into streams was judged unacceptable from the beginning and the need for data was limited

to demonstrating the impact of this type of animal waste disposal on surface water quality. Examples of effluent quality data and corresponding hydrological data from site D are presented graphically in Figures 19-24.

The stream bed at site D was relatively free of deposited solids during the early part of the study. Shortly thereafter, however, it was normally covered as deep as three inches with solids from swine wastes. These solids were primarily from wastes washed directly into the stream from the farrowing house and holding pens.

The number of animal units, H, was obtained by dividing an estimated total weight of swine in the farrowing house, the pens, and the drylots by 100 lbs. Since the swine wastes in the drylots remained away from the stream except during rainfall-runoff events while the wastes from the farrowing house and holding pens were washed directly into the stream every two days, the H values reported are somewhat lacking for a basis. Nevertheless, the significant linear correlation coefficients between H and the pollution indices suggests that the H values were important in determining the pollution indice values and loads on the stream.

Hydrological Data. Temperature variations during the study were small. This may account for the low correlation between the temperature and the pollution index values.

The stream flow hydrographs for site D (Figure 19) show peaks caused by washing wastes from the farrowing house and holding pens in addition to the normal responses to rainfall. The periods of wash-down are marked on the plots to the extent possible. Some periods of wash-down may have been overlooked.

Base flow rates (q_b) correlated better with the pollution indices than either q_t or q_o. The q_t value for data group D, obtained by averaging the flow rates at the times of sampling, was higher than the actual mean flow rate because the sampling times were commonly associated with surface runoff and wash-down events. The flow results presented in Table 7 were obtained by using $\overline{q}_b$ as the mean flow rate.

Pollution Indices. Indicator bacteria counts were exceptionally high in the stream samples from site D. The minimum FC value observed was obtained on March 30, 1969, just before the stream was subjected to wastes by direct discharge. During April the minimum was 14,500 col/100 ml. In May the minimum was 31,000 col/100 ml and in June 300,000 col/100 ml. During May and June the minimum values occurred after flushing with runoff.

TOC values were larger than BOD_5 values during the early part of the study but the reverse was true during the latter part. This indicates that wastes in the stream during the early part of the study were more oxidized than those in the latter phase. During the early phase, a larger portion of the wastes was from the drylots.

After the stream had become heavily loaded with wastes, TOC exceeded the BOD_5 for short periods during peak rate of runoff from

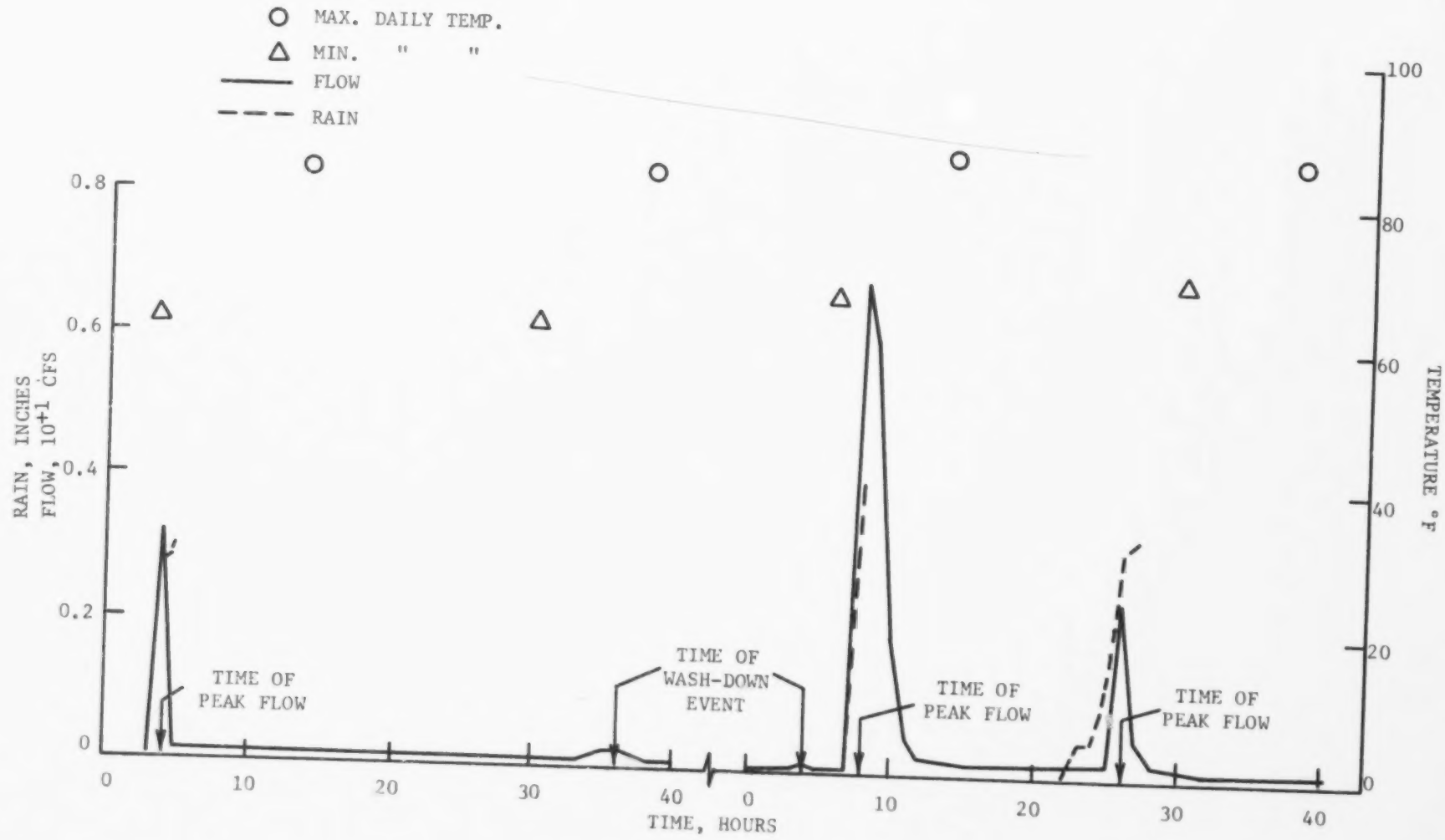

Figure 19. Hydrological Data, Site D, May 25-26 and June 12-13, 1969.

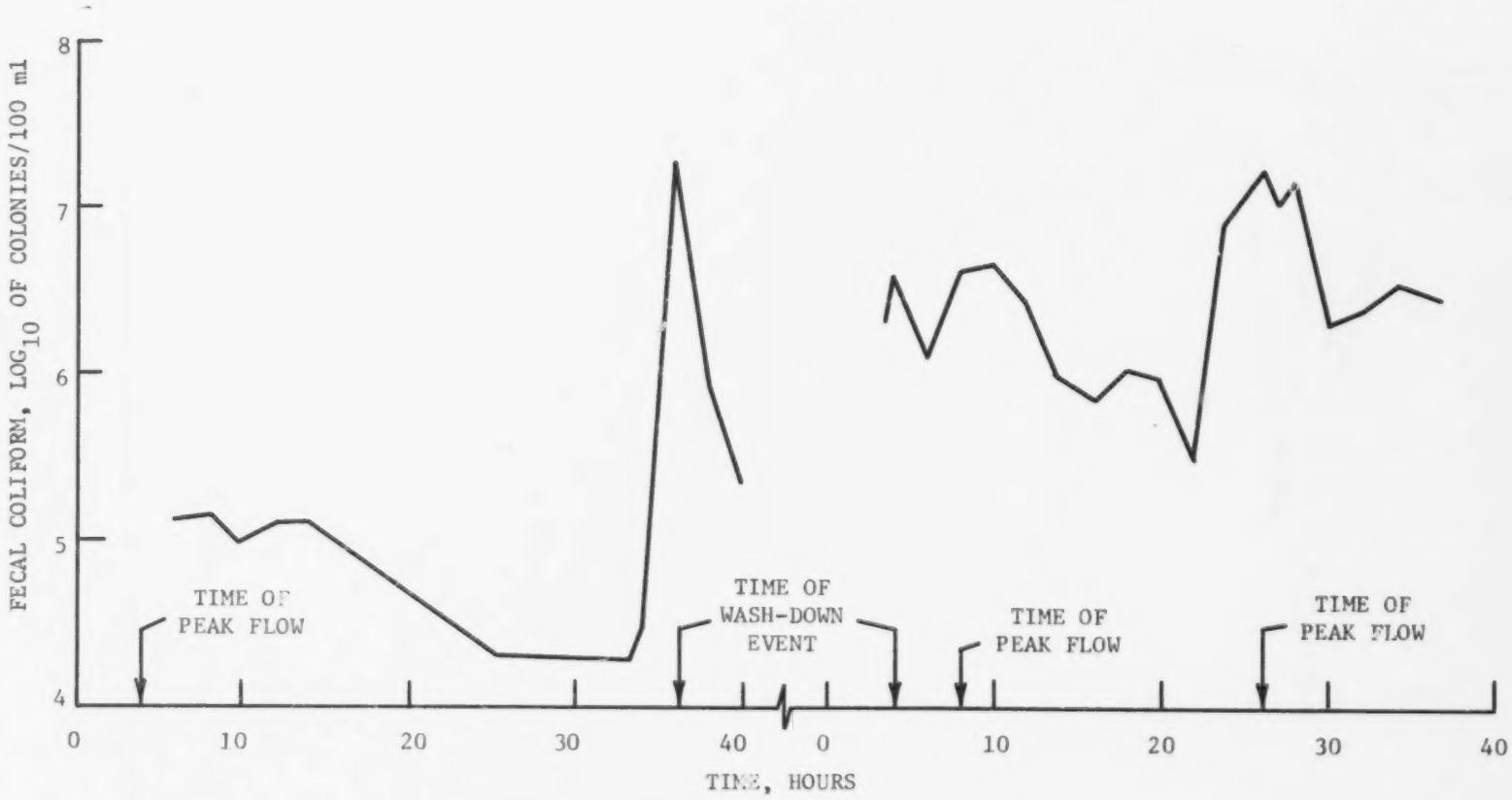

Figure 20. Fecal Coliform, Site D, May 25-26 and June 12-13, 1969.

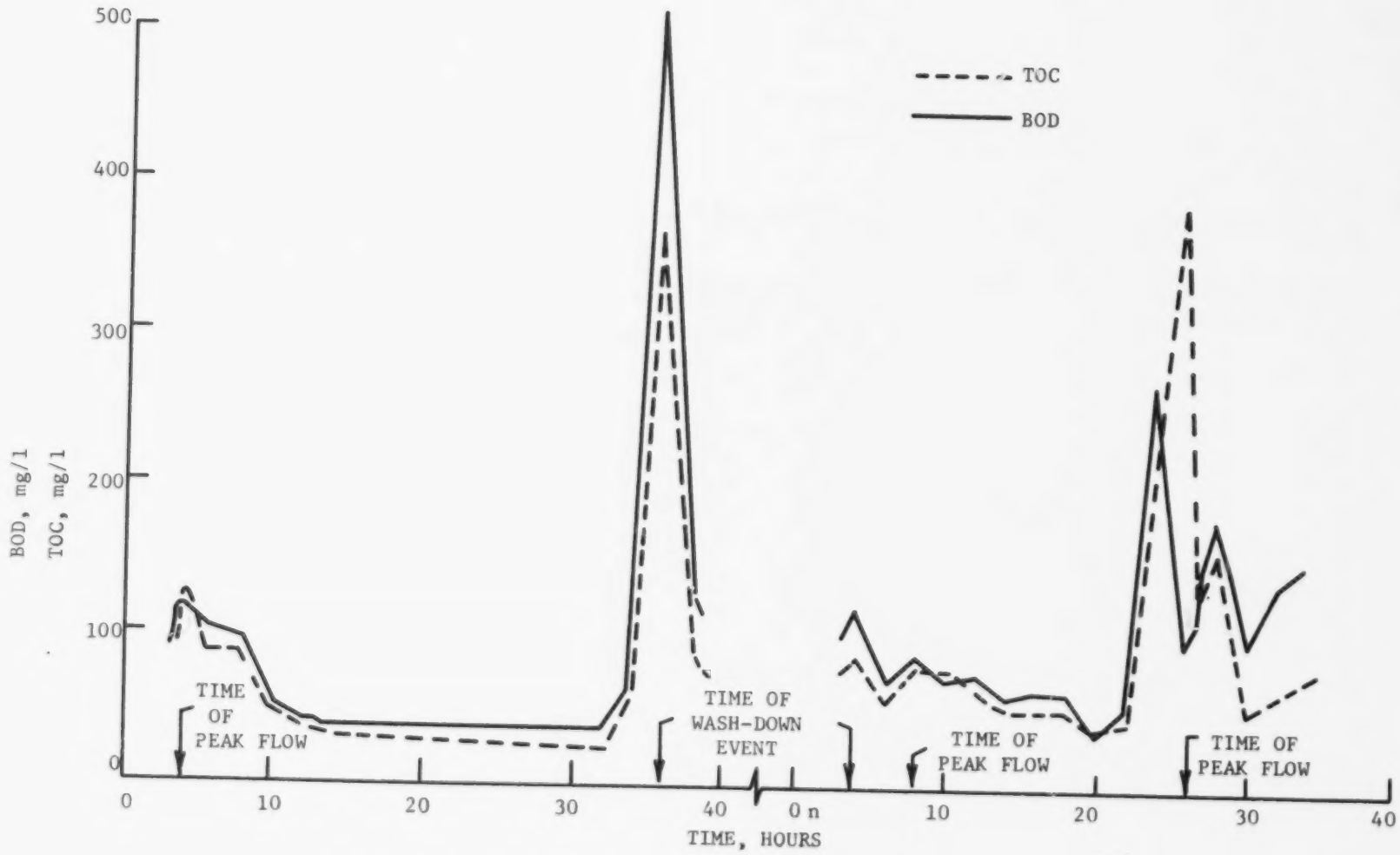

Figure 21. BOD_5 and TOC, Site D, May 25-26 and June 12-13, 1969.

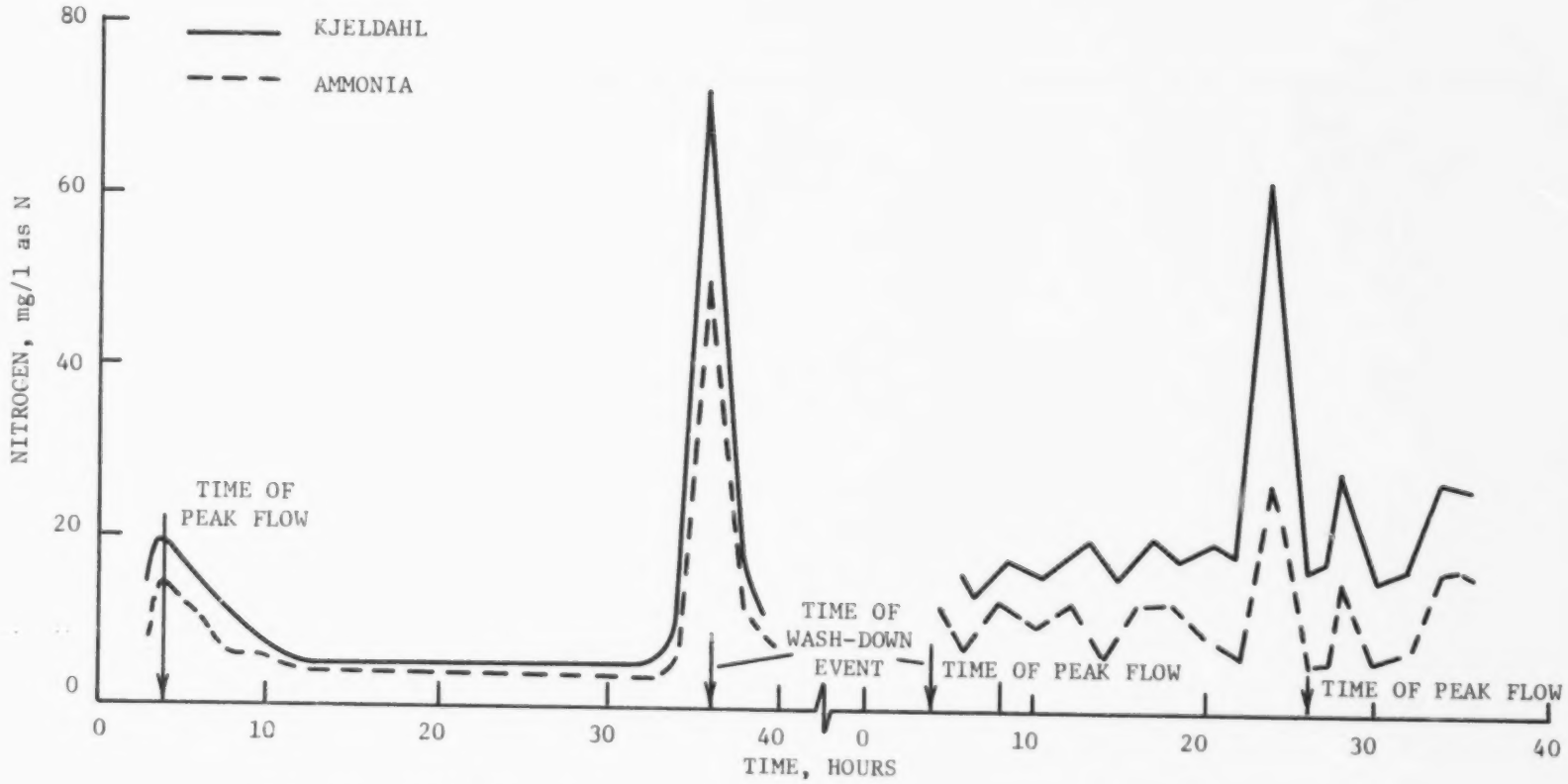

Figure 22. Kjeldahl and Ammonia Nitrogen, Site D, May 25-26 and June 12-13, 1969.

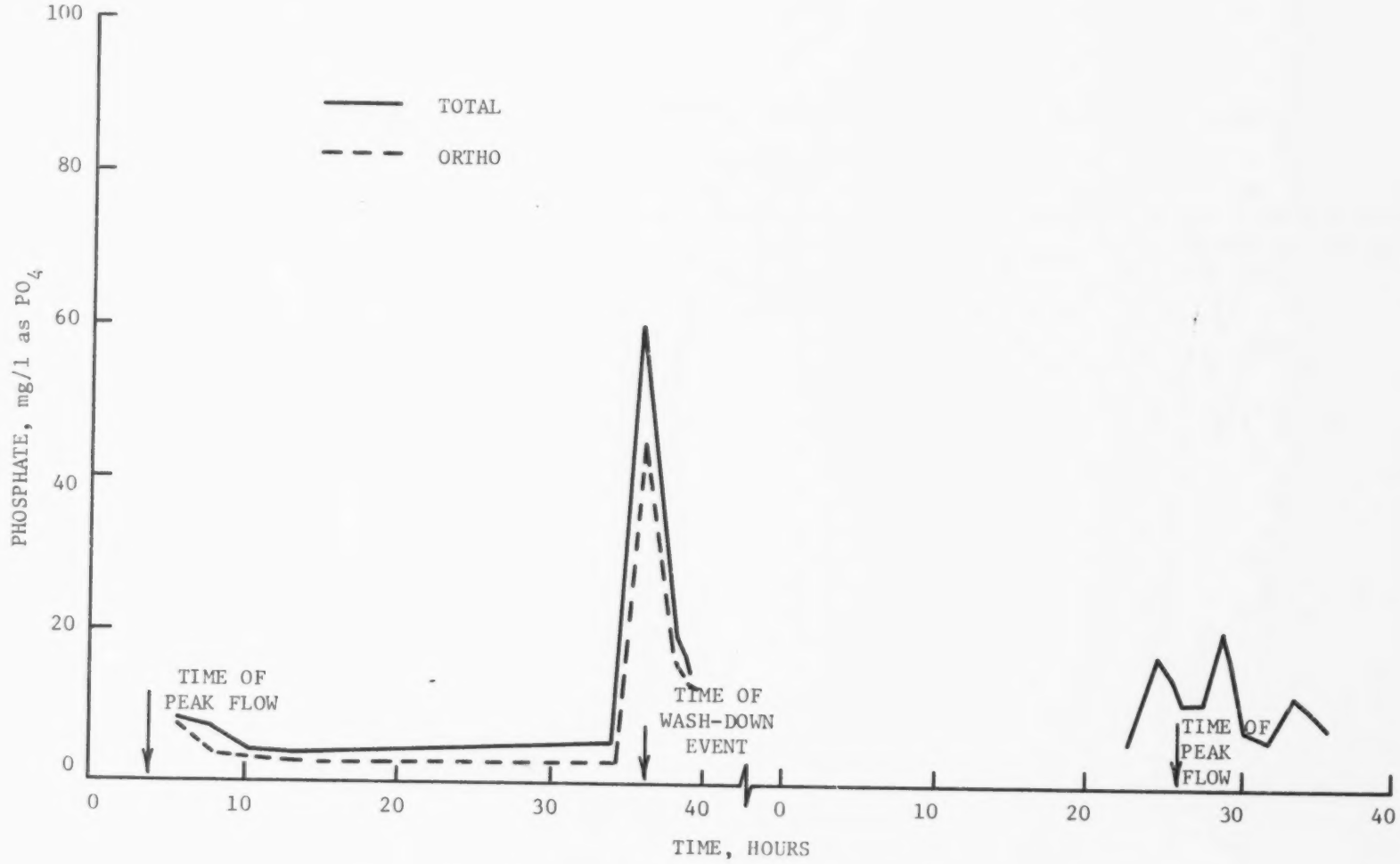

Figure 23. Phosphate, Site D, May 25-26 and June 12-13, 19691

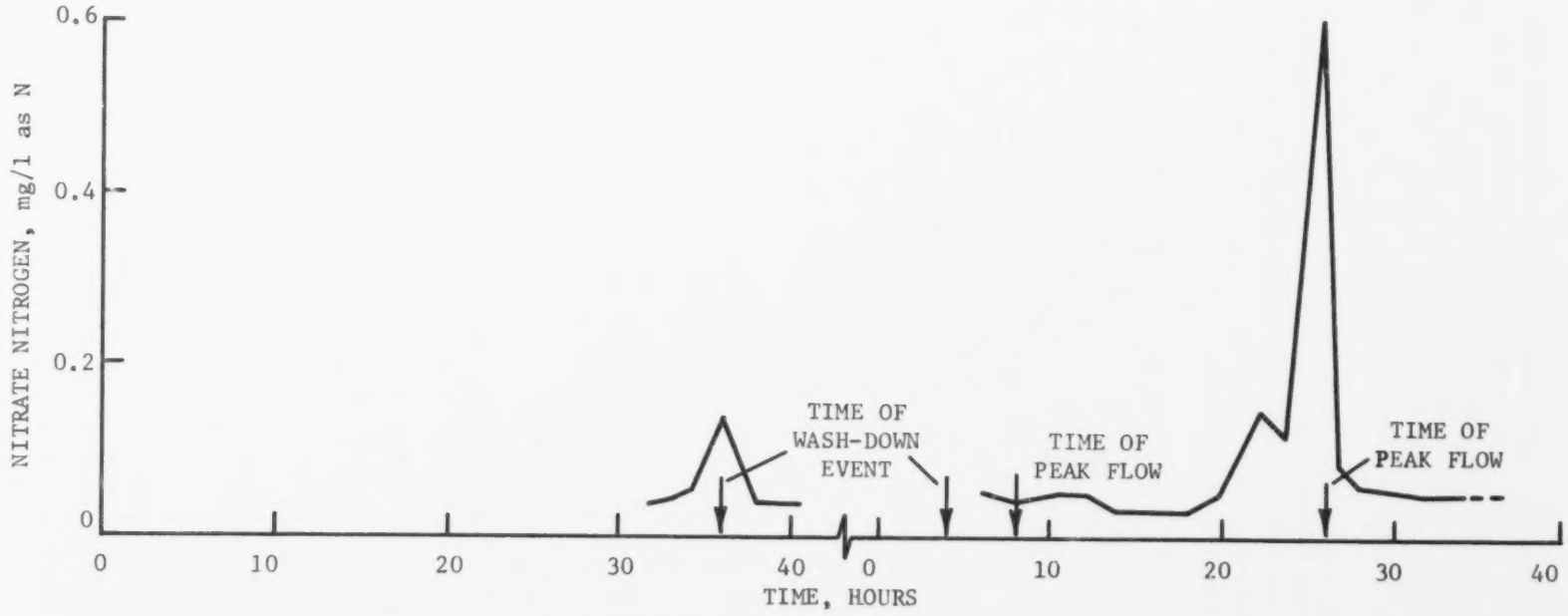

Figure 24. Nitrate Nitrogen, Site D, May 25-26 and June 12-13, 1969.

greater runoff events. This suggests that contributions of waste from land origin, e.g., the drylot operation, or from sources of more stable and/or less degradable materials were entering the stream. During the first part of the runoff event and shortly after peak runoff, the BOD_5 exceeded the TOC. This indicates that a major portion of the wastes in the stream was from the direct discharge sources.

Higher values of NO_3 were generally obtained during periods of surface runoff than during wash-down events. This suggests that the waste in the runoff waters had undergone considerable aerobic decomposition and further substantiates the explanation of the reversal in the BOV_5/TOC ratio during greater runoff events.

The wastes washed directly into the stream from the confinement growing areas not only caused high pollution indice values during the wash-down events but also caused high values during base-flow conditions. Furthermore, the large amounts of wastes deposited on the bed of the stream between runoff events caused the pollution indices to rise rapidly at the beginning of runoff events, a first flush effect. During light runoff events, the pollution indices normally peaked at peak flow and showed a corresponding decrease with runoff rate. However, during larger runoff events, the pollution indices peaked before peak runoff and showed a decrease during high runoff rates followed by a second peak as runoff decreased. After this second peak, they showed a corresponding decrease with runoff rate to values below base-flow contents. As runoff stopped, the indices returned to the base-flow values. This phenomenon is illustrated by Figures 19-24.

Results of calculations of the amount of pollution/day/H carried by the stream at site D are shown in Table 7. The value for FC/day/H was obtained by multiplying the mean of all FC measurements made on the samples from stream D by $\overline{q}_b$. The value for TC/FC was obtained from all paired TC and FC measurements made on the samples from stream D. The other results were obtained in a similar manner.

Land Runoff Studies

Examples of runoff water quality data and corresponding hydrological data for sites E, F, and K are presented graphically in Figures 25-29.

Wastes spread on site E were evaluated by dividing the product of the average H and the time period of waste production in the confinement growing operation into the amount of waste produced to obtain the amount of waste per H per unit time. This value was then divided into the appropriate rate of spreading selected from Figure 2 to obtain H values for wastes spread. These values were added to the H values for hogs on pasture and the sum was rounded off to give the values reported for site E.

Site F, the control area, was free of swine and all other domestic animal wastes. Thus, H is reported as 0. H values reported for site K were obtained from reports by the swine producer of the total weight of hogs in the drylots.

Table 7. Summary of the effect of discharging swine wastes directly into stream D

Variable		Max	Mean	Min	Fresh waste
H		300	245	100	
q	cfs	6.3	.110[a]	.057	
	gal/day/H		290		
FC	col/100 ml	36 x 10^6	2.7 x 10^6	150	
	col/day/H		28.5 x 10^9		8.9 x 10^9[b]
TC	col/100 ml	24 x 10^6	4.0 x 10^6	150 x 10^3	
	col/day/H		44 x 10^9		
TC/FC			1.5		
BOD_5	mg/l	520	72.7	6.8	
	lb/day/H		.167		.32[c]
TOC	mg/l	380	52.9	10.5	
	lb/day/H		.122		
BOD_5/TOC			1.20		
N	mg/l	72	13.0	2.0	
	lb/day/H		.030		.048[c]
TN/NH_3-N			1.40		
PO_4	mg/l	60	6.9	.5	
	lb/day/H		.016		.035[c]
TP/OP			1.5		

[a] q_b.

[b] Gieldrich (1966).

[c] Muehling (1969).

Linear correlation coefficients for H with most of the pollution indices showed significant correlations for data groups E and K. At site K, H was significantly correlated at the 0.01 level with TC, BOD_5, TOC, TN, and NO_3. The correlation coefficient between H and TC should

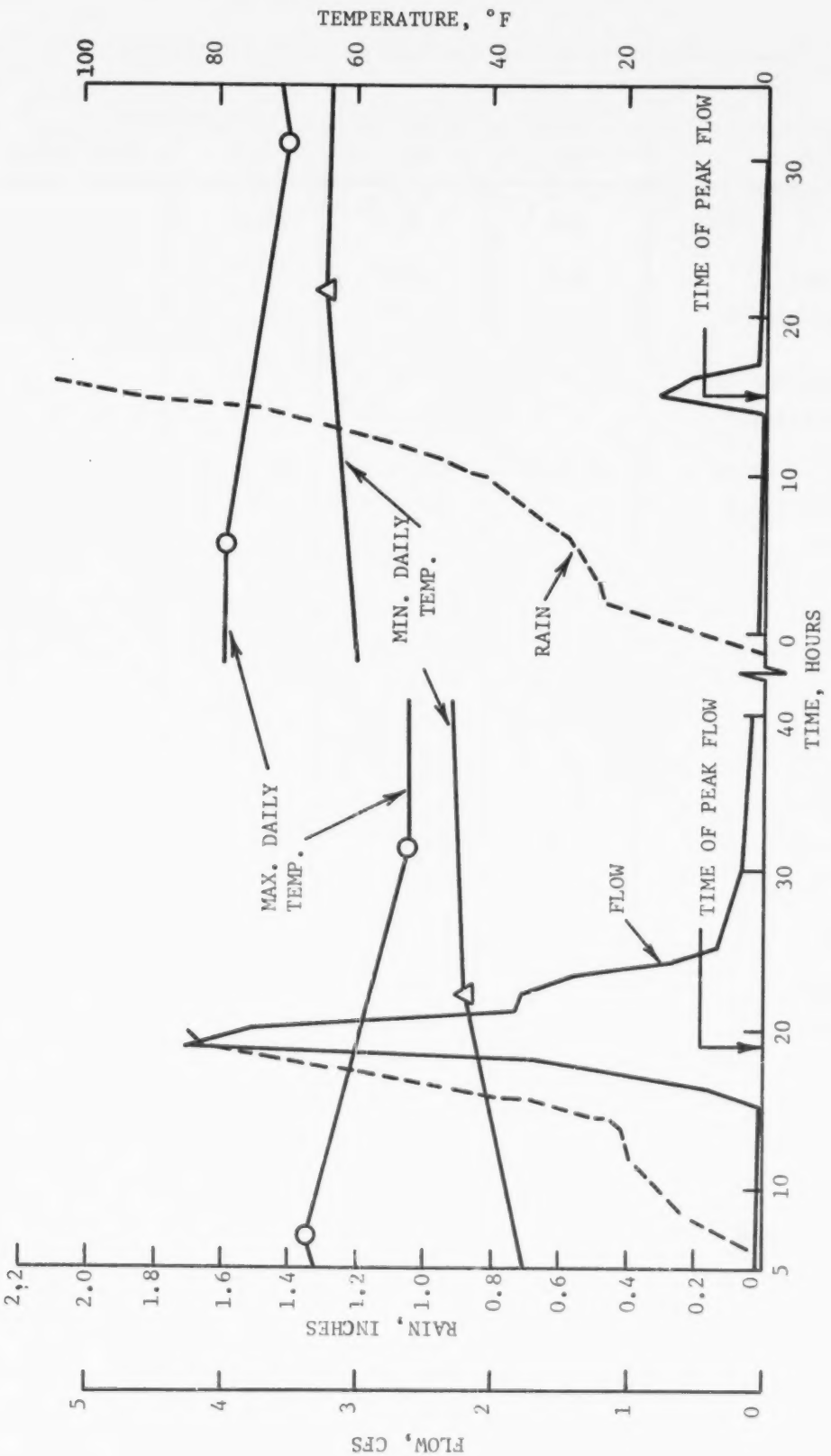

Figure 25. Hydrological Data, Site E, March 18-19 and May 19-20, 1969.

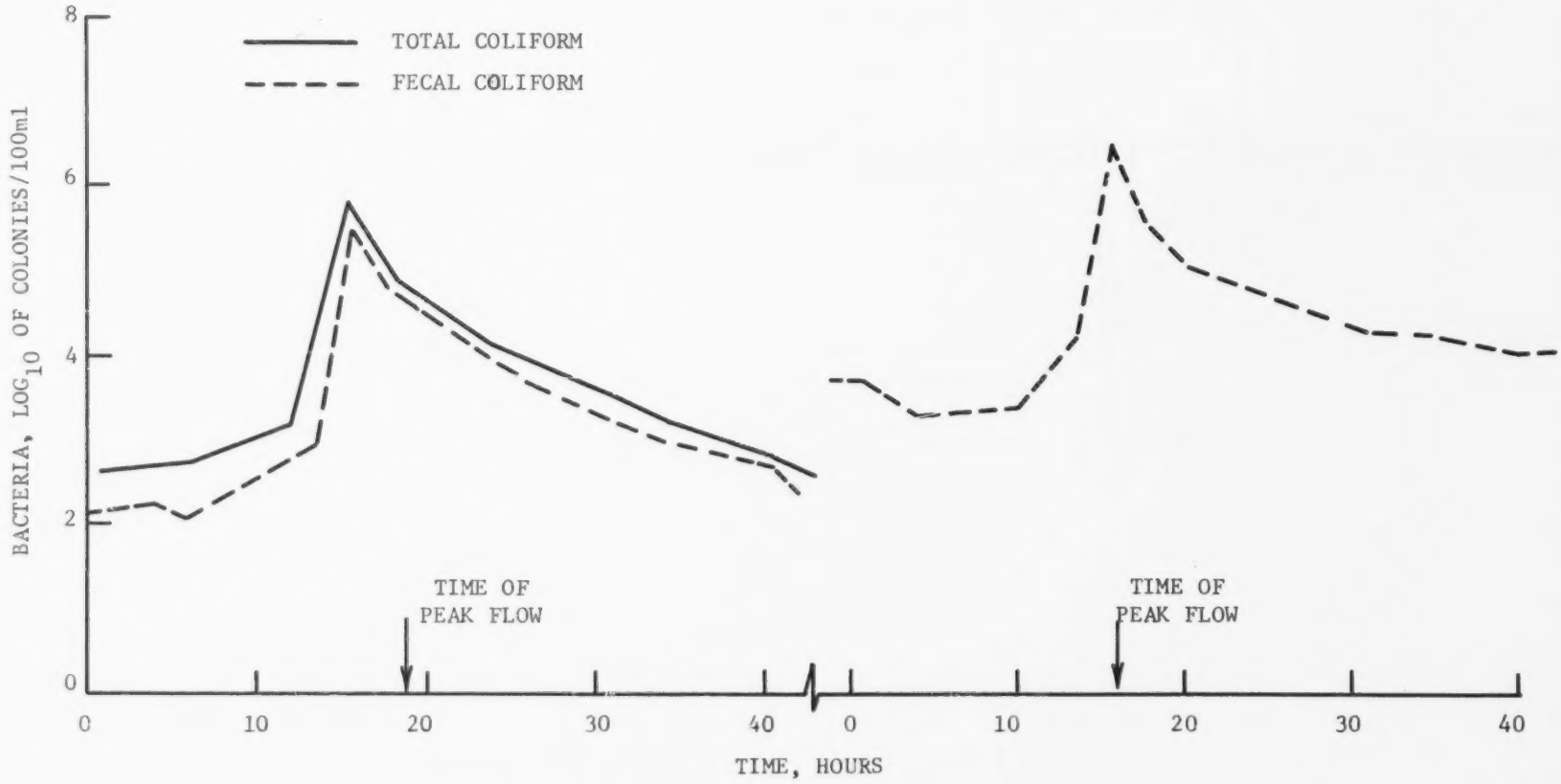

Figure 26. Bacteria, Site E, March 18-19 and May 19-20, 1969.

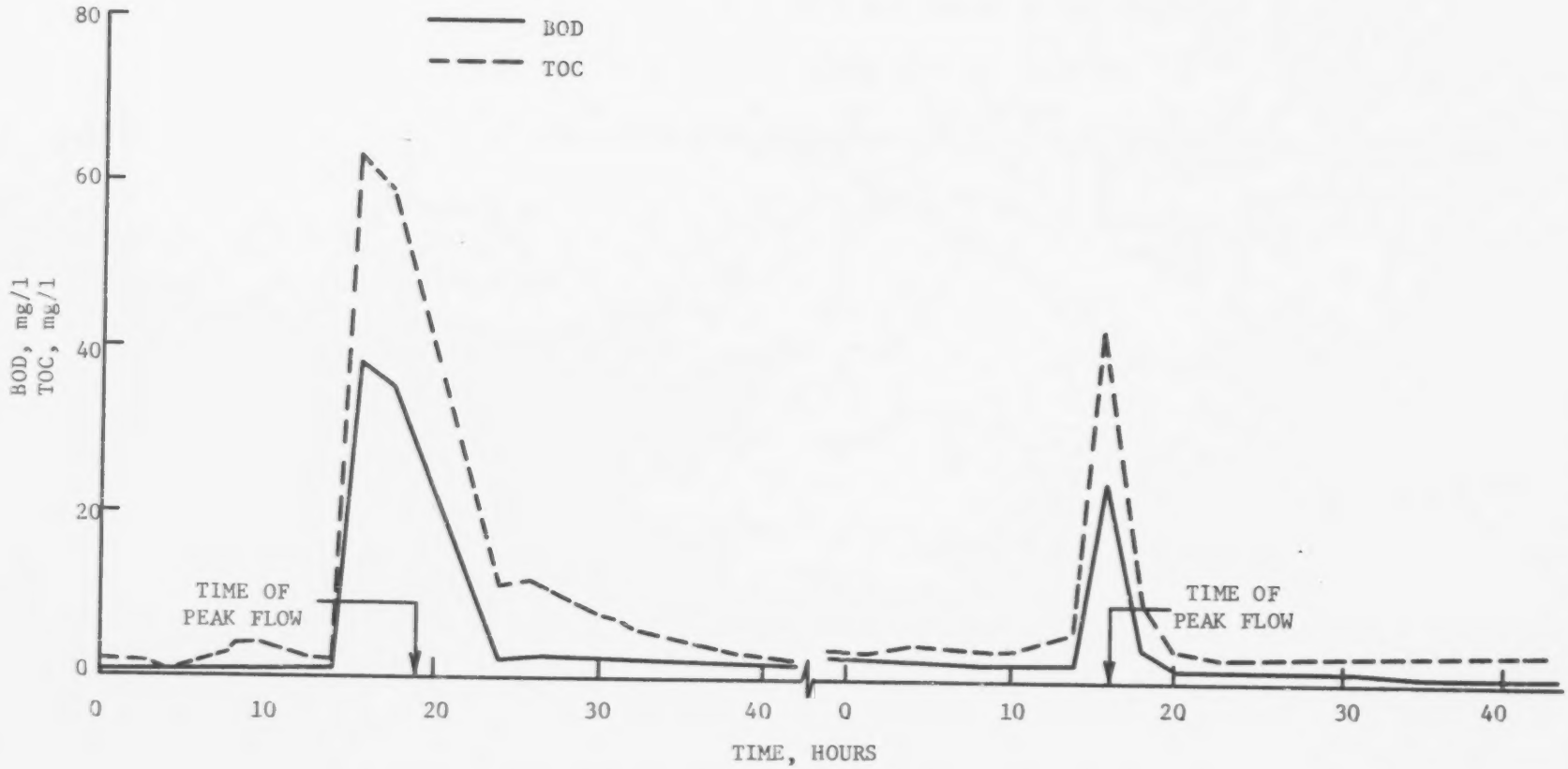

Figure 27. BOD_5 and TOC, Site E, March 18-19 and May 19-20, 1969.

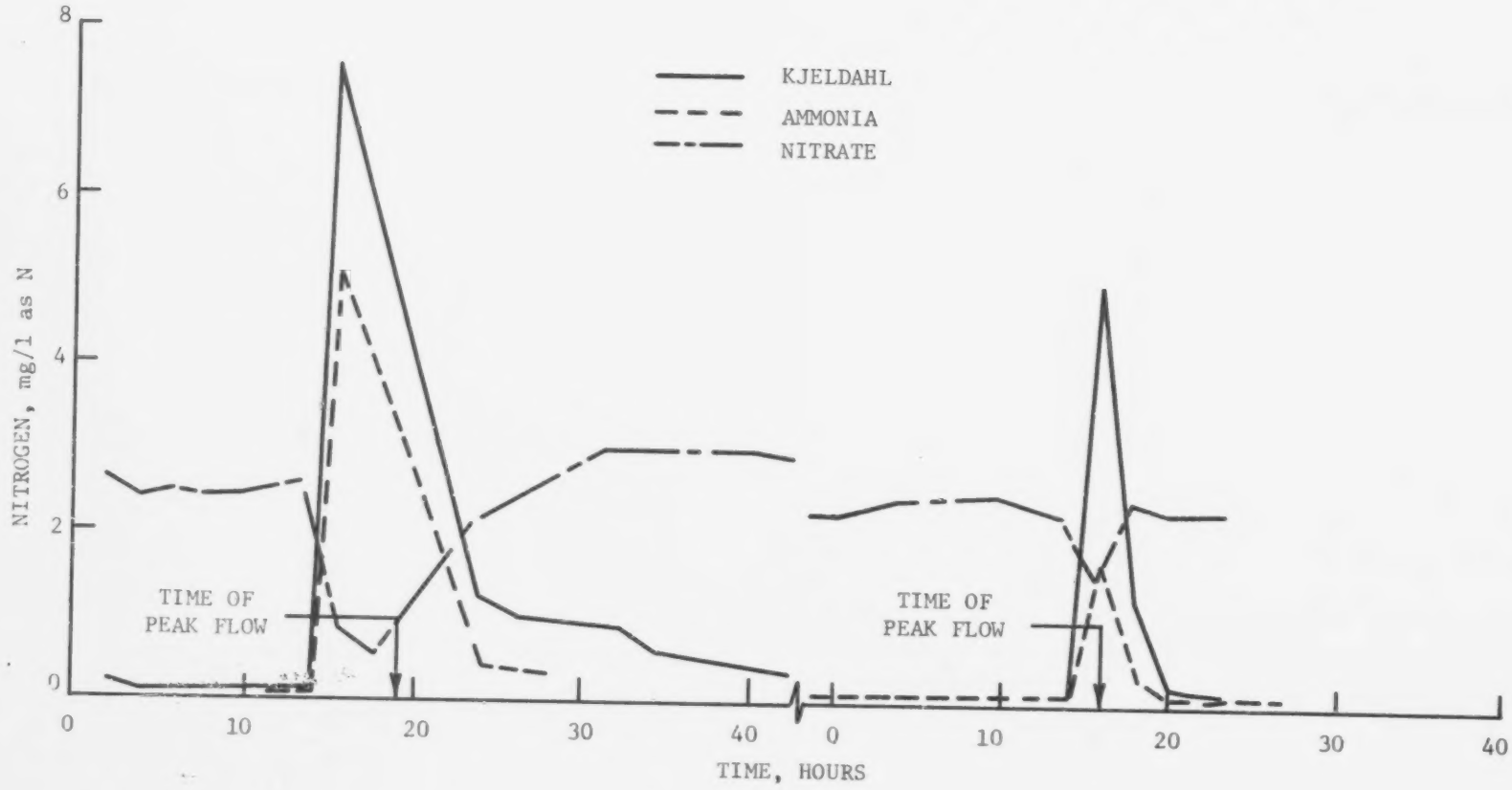

Figure 28. Kjeldahl, Ammonia and Nitrate Nitrogen, Site E, March 18-19 and May 19-20, 1969.

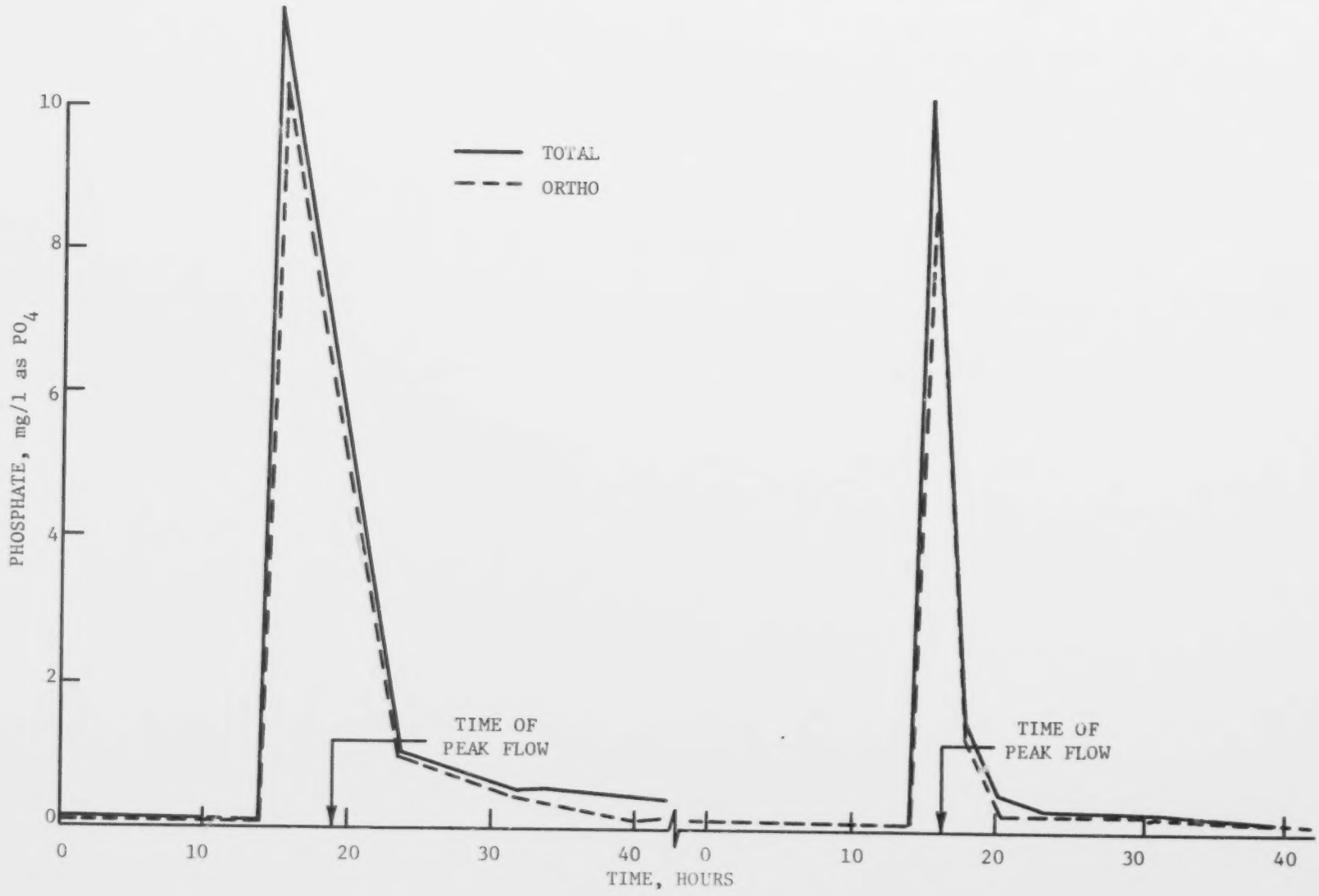

Figure 29. Phosphate, Site E, March 18-19 and May 19-20, 1969.

not be regarded as meaningful since only 9 TC values were included and 8 of these were obtained for a constant H value. The poor correlations within most data subsets was partially due to the small variations in the H value throughout the periods covered by these data groups. When all data for a given site were combined, the correlations between H and the other indices were evident because H varied during the periods covered. Even so, the correlation coefficients for data group E were rather low. This was also the case when data from sites E and K were combined as data group EK. These latter correlations suggest that the H values reported for site E may have been poor. Since better correlations were obtained from site K, solely a drylot operation, than from site E, the problem was probably associated with H values. If this were the case, then the problem probably arose from failure to consider the decomposition of wastes in the pits before it was spread on the land and the differences in fate of the spread wastes compared to those voided in drylots. Observations of the spread wastes revealed that the solids were well dispersed. Thus, there was greater opportunity for attachment to the soil than when solids were excreted in lumps on the drylots. Also, the wastes were spread on a heavy growth of grass and a considerable portion lodged above the ground surface. This may have allowed rapid decay with decreased movement to the stream.

Another probably cause for the low correlations with H is that only a small part of the total watershed was subjected to swine wastes. As suggested by the study at site F, natural pollution from areas free of domestic animal wastes may account for a substantial portion of the total stream pollution associated with land on which animal wastes are disposed.

Pollution indice values for the raw wastes spread on site E varied widely depending on the amount of water involved and the age of the wastes. The data obtained from analyzing 18 samples collected from the manure wagon used to spread the wastes gave the following results:

Indice	Max	Mean	Min	Units
TC	130×10^6	27×10^6	6×10^6	col/100 ml
FC	87×10^6	13×10^6	4×10^6	col/100 ml
BOD	62,000	25,000	4,600	mg/l
TOC	43,000	14,000	3,300	mg/l
TS	344,000	220,000	5,700	mg/l
VS	264,000	180,000	4,600	mg/l
TN	12,700	4,100	320	mg/l
$TP\text{-}PO_4$	8,500	2,700	115	mg/l
$OP\text{-}PO_4$	7,000	1,500	75	mg/l

Variations in indice values between samples were expected because of the differences in the amount of dilution and sampling error. When compared to wastes entering a lagoon, the much higher indice values obtained for these wastes were due to differences in dilution.

Hydrological Data. Generally, minimum temperature, T_n, was a little better correlated with the pollution indices for land runoff samples than was maximum temperature, T_x. The correlations of T_x and T_n with pollution indices were low for the data groups containing only data from sites E and K. The study period for site E ran from the beginning of 1969 through August 1969 and gave temperature variations large enough to point up correlations if they had existed. The study period for site K was limited to the spring and summer of 1969; and thus, the temperature variations were small and may account partially for the poor correlations.

Variations in the hydrographs for the streams located at the land runoff sites were generally associated with rainfall-runoff events. Small daily variations were discernible only at site K. Because the rainfall and flow data collected during the study were insufficient to allow development of stream flow prediction equations, measured streamflow values were used in the regression analyses that were performed to obtain predictions of pollution indice values in the streams.

Linear correlation coefficients between q_b and pollution indices were slightly better than for either q_t or q_o for data group F. However, subsets of data group F often showed that the correlations were better for q_t and q_o. At sites E and K, the pollution indices were more closely related to q_t and q_o. Since the swine wastes reaching the streams were hypothesized to be associated with overland flow, q_o was selected as an independent variable for the regression analyses.

Since sampling was commonly associated with rainfall-runoff periods, the q_t values for sites E, F, and K obtained by averaging the flow rates at the time of sampling were greater than the average flow rates. Closer estimates of the average flow rates were given by the $\overline{q_b}$ values. The q_b values at times of sampling were higher than the average q_b values because q_b also increased during rainfall-runoff periods. The results presented in Table 8 were obtained using $\overline{q_b}$. The flow rates represent water yields of 9.9, 12.6, and 8.2 in./ac/yr for sites E, F, and K, respectively. Larger maximum flow rates were obtained at sites E and K than at site F even though the drainage areas at E and K were smaller. A major factor causing this was the differences in slopes and surface cultures. Basins E and K were farmed more intensely and row crops were grown on poorer classes of land than was true for watershed F. Thus, higher rates of runoff, and erosion, resulted.

Table 8. Rates of streamflow from the land runoff sites

GROUP (Site)	max q_t	$\overline{q_b}$	min q_t	$\overline{q}$		
		cfs		$10^6 ft^3/yr$	gal/day/ac	gal/day/H
E	4.9	.040	.021	1.26	740	51
F	2.1	.109	.025	3.45	940	-
K	5.4	.047	.001	147	590	154

Bacteria Indices. Bacteria counts rose considerably during runoff events at sites E, F, and K. Correlations of FC and TC with q_t and q_o were good for several of the subsets of data groups E, F, and K. The correlations were also good for data group K; but when all data for site E were examined, there was almost no correlation between these variables. The same was true for the data from site K. Over the long period, then, the relations between flow and bacteria levels were overshadowed by other more important factors.

Both TC and FC counts increased for all flow conditions at sites E and F as the study progressed. This was probably caused by temperature differences, because the temperature rose during the course of the study and provided a warmer and more favorable growing environment. The significant positive, although low, correlation coefficients for data groups E and F suggest that the increase in temperature during the study period at least partially caused the observed increases.

In general, correlations between FC and TC and the other pollution indices were good for sites E and K. The poorer correlations at site F were related to low indice values. For example, the $\overline{NH_3\text{-}N}$ value for group F was only 0.3 mg/l.

Results of calculations of the bacteria carried by the streams are shown in Table 9. The value for FC/day/H for data group E was obtained by multiplying the mean of all FC measurements made on samples from site E by $\overline{q}$ for data group E from Table 8. The value for TC/FC for data group E was obtained from all paired TC and FC measurements made on samples from stream E. The other results were obtained in a similar manner. Data group F2 (control site subset) is included in Table 9 and the following discussion because it covers the same period of data collection as data group K.

Table 9. Bacteria in streamflow from land runoff sites

GROUP (Site)	FC col/100 mo max	FC col/100 mo mean	FC col/100 mo min	FC 10^6 col/day/ac	FC 10^6 col/day/H	TC/FC
E	8.3×10^6	189×10^3	2	5,120	358	2.1
F	$.8\times10^6$	10×10^3	1	330	-	3.9
K	11.4×10^6	365×10^3	1450	8,200	2,040	2.4
F2	$.8\times10^6$	21×10^3	19	750	-	3.8

The TC/FC ratio was generally lower on sites E and K than on site F. This followed the expected pattern because the source of FC is primarily from animal wastes whereas TC may arise from other sources as well; e.g., soil. Thus, the lower TC/FC ratios at sites E and K reflect a larger portion of animal wastes in the stream waters. The TC/FC ratio was also lower at all sites during periods of rainfall-runoff than during periods of no surface runoff. This suggests that during rainfall-runoff periods, some animal wastes were washed into streams, including the control stream (wildlife).

BOD_5 and TOC. Excellent linear correlations generally existed between BOD_5 and TOC at sites E and K whereas the correlation coefficients at site F were generally lower. Essentially, all correlations were positive and significant at the 0.01 level. Better correlations resulted when the stream samples were more polluted. When the streams contained low amounts of biodegradable wastes, the BOD_5 values were questionable because the amount of oxygen used in the test was generally below the recommended amount of 2 mg/l.

BOD_5 and TOC usually showed good correlation with the other pollution indices for the land runoff data groups. Thus, both BOD_5 and TOC provided good measurements of the pollution loads on the streams.

Results of calculations of BOD_5 and TOC carried by the streams are shown in Table 10. The value for BOD_5/day/H for data group E was obtained by multiplying the mean of all BOD_5 measurements made on samples from site E by $\bar{q}$ for data group E from Table 8. The value for BOD_5/TOC for data groups E was obtained from all paired BOD_5 and TOC measurements made on samples from stream E. The other results were obtained in a similar manner.

TOC values were larger than BOD_5 values for the samples collected from the three land runoff sites indicating that the wastes which reached the streams were relatively well oxidized. The higher ratios for sites E and K suggest that wastes entering the streams from the swine production areas were generally less degraded biologically than natural wastes from the control site.

Nitrogen. Ammonia nitrogen was a higher percentage of the TN on the waste watershed than on the control. The maximum TN value of the 317 land runoff samples analyzed was 15.6 mg/l. This sample was collected from site F. The average TN content of all 317 samples was 1.2 mg/l. The TN concentrations under base flow conditions were 0.1, 0.2, and 0.5 mg/l at sites E, F, and K, respectively.

The maximum NH_3-N value of the 186 samples analyzed was 6.8 mg/l. As with TN this sample was also collected from site F. The maximum values at sites E and K were 6.0 and 1.7 mg/l, respectively. The average of all 186 samples was 0.4 mg/l. The means of the samples for sites E, F, K, and F2 were 0.6, 0.3, 0.4, and 0.4 mg/l, respectively.

The NO_3-N content was about 0.01 mg/l under base flow conditions at sites F and K and was near 2.6 mg/l at site E. The nitrate concentrations on watershed E were generally inversely related to surface runoff. This was particularly true during the winter and early spring period. Later in the study, the NO_3 content showed both increases and decreases with increased flow rates. The increases were associated with high rates of surface runoff. Essentially, all data groups for sties F and K data showed positive correlation coefficients.

Results of calculations of the nitrogen carried by the stream are shown in Table 11. The value for N/day/H for data group E was obtained by multiplying the mean for all TN measurements made on samples from

Table 10. BOD_5 and TOC in streamflow from the land runoff sites

GROUP (Site)	BOD_5					TOC					BOD_5/TOC
	mg/l			lb/day/ac	lb/day/H	mg/l			lb/day/ac	lb/day/H	
	max	mean	min			max	mean	min			
E	70.0	4.7	.1	.028	.0020	85.0	9.6	1.0	.057	.0040	.51
F	16.8	2.0	.1	.015	-	380.0	14.6	3.0	.111	-	.17
K	35.0	6.4	.9	.031	.0079	140.0	17.6	5.8	.087	.0216	.36
F2	16.8	2.7	.1	.021	-	380.0	22.7	5.0	.177	-	.18

Table 11. Nitrogen in streamflow from the land runoff sites

GROUP (Site)	TN					NO_3-N					TN/NH_3-N
	mg/l			lb/day/ac	lb/day/H	mg/l			lb/day/ac	lb/day/H	
	max	mean	min			max	mean	min			
E	12.0	1.1	.1	.0068	.00047	9.99	2.58	.55	.0159	.00110	2.34
F	15.6	1.2	.1	.0094	-	.68	.20	.01	.0016	-	4.00
K	7.7	1.4	.3	.0069	.00180	2.00	.30	.01	.0015	.00039	3.75
F2	15.6	1.6	.1	.0125	-	.50	.17	.01	.0013	-	3.00

site E by $\overline{q}$ for data group E from Table 8. The value for TN/NH_3-N for data group E was obtained from all paired TN and NH_3 measurements made on samples from stream E. The other results were obtained in a similar manner.

Phosphate. TP and OP concentrations followed the same hydrograph pattern as the other indices, except NO_3 at site E, of increasing and decreasing with flow rates. Base flow TP contents were between 0.25 and 1 mg/l. Maximum TP values occurred for the samples that contained the largest amounts of soil. This indicates that the phosphorus entering the streams was closely related to erosion.

Results of calculations of the phosphorus carried by the streams are shown in Table 12. The value for PO_4/day/H for data group E was obtained by multiplying the mean of all TP measurements made on the samples from stream E by the $\overline{q}$ for data group E from Table 8. The value for TP/OP for data group A was obtained from all paired TP and OP measurements made on the samples from stream E. The other results were obtained in a similar manner. Phosphorus entering the streams was mainly OP and thus was immediately available to plants.

Table 12. Phosphate in streamflow from the land runoff sites

GROUP (Site)	PO_4					TP/OP
	mg/l			lb/day/ac	lb/day/H	
	max	mean	min			
E	17.0	1.2	.1	.0074	.00051	1.16
F	4.0	.2	.1	.0016	-	1.00
K	13.0	1.9	.1	.0094	.00234	1.15
F2	4.0	.3	.1	.0024	-	1.00

Discussion. There was no evidence of pollution from swine waste spreading at site E during periods of dry-weather flow except for nitrate. While negligible, there was some indication of pollution from the drylot operation at site K which is attributed to erosion. During rainfall-runoff events, however, pollution indices from runoff at sites E, F, and K rose to unexpectedly high levels in response to increasing rates of flow. With the possible exception of bacterial densities, pollution through surface runoff from areas utilized for land disposal of swine wastes was not markedly higher than from the control watershed which was entirely free of farm animals.

The higher than expected NO_3 content at site E suggests the possibility of groundwater pollution and discharge in the base flow of the stream. Since the nitrate concentration at site K was not significantly different from that at site F, the nitrate in the stream at site E is

assumed to be due to the wastes spread on the watershed and not the drylot source. The 135,000 gal of raw wastes spread during the study period at site E was applied to only five acres of the forty-acre watershed. If this same rate, 27,000 gal/acre, had been applied to the total watershed, the resulting NO_3-N content in the groundwater and base flow would have been 18 mg/l. This value is 1.8 times the maximum value specified by the Public Health Service for nitrate nitrogen in drinking water. The application period for the wastes at site E was about six months. Thus, a yearly application rate of 27,000 gal/acre over the entire watershed would maintain the NO_3 content below the acceptable drinking water standard. At this rate the disposal area required would be 1 ac/100 H when the entire watershed is used. In addition, this lower rate of application would enable plants to use more of the nitrogen and an even smaller amount would then enter the stream via groundwater.

The effects of animal wastes on the study sites were often overshadowed by watershed factors, particularly the slopes and surface cultures. These were important in determining the amount of erosion and, thus, the amount of pollution reaching the stream. For example, the PO_4 loads on stream K when compared to stream E suggest that five times as much PO_4 per animal reached the stream at site K as at site E.

The lower bacteria densities from the control watershed as compared to the generally higher values from the waste watersheds suggests the possibility of some stream contamination from runoff due to land disposal of animal wastes. The BOD/TOC ratio for the watersheds tends to confirm this assumption. Differences in the calculated numbers of colonies per day per H between sites E and K suggest that the occasional higher numbers at site K were due to the swine having direct access to the stream.

The data obtained from site E during March 18-19 and May 19-20, 1969, (Figures 25-29) are representative of data obtained from the land runoff sites. All pollution indices except NO_3 at site E increased substantially with surface runoff and paralleled the hydrographs with extended drag-out on cessation of surface runoff. Changes in magnitude of the indices were generally greater for higher rates of surface runoff. This is exemplified by comparing the values obtained during the March and May periods except for bacteria counts. Base-flow bacteria counts were also higher during the second period than during the first. This followed the general trend of higher counts during warmer and more favorable temperature periods. Another reason for the higher bacteria values during the May period is the difference in surface culture. The entire basin at site E was well protected with vegetation during the March period. Land preparation had begun during the May period and some areas were subject to easy erosion. A less likely reason may have been that wastes were spread immediately preceding and during the rainstorm in the May period whereas the most recent waste spreading in the March period was five days preceding surface runoff.

The data shown in Table 13 from sites E and F illustrate the effect of runoff rates on pollutional discharges. The period of surface runoff was about 10 hours at site E and 25 hours at site F during the period March 18-25. The peak-flow rate was 90 times the base-flow rate at site E and only 20 times at site F.

Table 13. Response of stream pollution to flow rate - March 18-25, 1969

Variable	Waste Watershed (site E)		Control Watershed (site F)	
	Base Flow	Peak Flow	Base Flow	Peak Flow
q_t, cfs	.04	3.70	.114	2.30
FC, col/100 ml	45	400,000	19	6,500
TC, col/100 ml	120	500,000	20	8,667
BOD_5, mg/l	.5	39.0	1.5	4.6
TOC, mg/l	1.0	63.0	5.0	21.5
TN, mg/l	.1	12.1	.1	3.0
NH_3-N, mg/l	.1	5.1	.1	.2
NO_3-N, mg/l	2.65	.55	.15	.46
TP-PO_4, mg/l	.1	9.0	.1	.7
OP-PO_4, mg/l	.1	8.2	.1	.4

Dairy Waste Study

Hydrological Data

The correlations of T_x and T_n with the pollution indices were low at the dairy sites although the temperature variations during the study were large enough to point up correlations if they had existed. Also, the linear correlation coefficients between q_t, q_b, and q_o with the pollution indices showed that the flow rates were poor measures of pollution in the streams. q_t and q_o were usually better correlated with the pollution indices than was q_b and the rate of streamflow was a better measure of the degree of pollution in stream H than in stream J.

The flow data presented in Table 14 were obtained by using the average of the base-flow rates in the stream at the times of sampling. The flow rates represent yields of 7.8 and 30.7 in/ac/yr from sites H and J, respectively. Two major factors attributed to the differences in yields. The surface culture on watershed J was poor due to the dense concentrations of animals and the building sites, while vegetation generally covered the entire watershed at site H. This resulted in more surface runoff at site J than at site H. Although watershed J was smaller than watershed H, the amount of wash water dumped into the stream was greater at site J due to the larger number of animals and the use of more wash water per animal necessitated by the poorer job of solids removal before wash-down.

Pollution Indices

All pollution indices were high in the streams receiving dairy wastes. Fecal coliform counts were exceptionally high. Stream J was more polluted than stream H. Visual observations of the amounts of solid animal wastes carried by the streams showed that stream H was relatively free of solids while stream J was more heavily loaded than stream D (which received direct discharges of swine wastes).

Correlations between pollution indices were quite high. BOD_5 and TOC generally showed sufficient correlation with the other indices to suggest either as a good measure of the degree of stream pollution and the amount of dairy wastes which entered the stream. COD and NO_3 were often poorly correlated with the other indices which suggests they were the poorer measures of stream quality.

Results of calculations of the amount of pollution carried by the dairy streams are shown in Table 14. The values of FC/day/cow at site H were obtained by multiplying the mean of all FC measurements made on the samples from stream H by q_b for stream H. BOD_5/COD ratios at site H were obtained from all paired BOD_5 and COD measurements made on the samples from stream H. The other results were developed in a similar manner. The data in Table 14 show that the FC was 875 percent at site H and 1340 percent at site J of the average production rates from fresh cow wastes reported by Gieldrich (1966). The BOD_5 was 6 percent and 23 percent, the COD was 11 percent and 16 percent, and the N (TN plus NO_3-N) was 10 percent and 10 percent for sites H and J, respectively, of the average production rates for fresh dairy cow wastes reported by Witzel, et al (1966).

Discussion

The exceptionally high values of FC carried by the dairy streams suggest an overgrowth of bacteria occurred in the streams above the sampling points. This overgrowth was limited to warmer weather. During the winter period, the FC counts in the streams were low which suggests that most FC bacteria died off before reaching the sampling station. An overgrowth of FC was also observed in stream D which was subjected to fresh swine wastes by direct dumping.

Even though the pollution indices other than FC indicated that only fractions of the dairy wastes reached the streams, the amounts were still sufficient to cause gross pollution conditions. For example, the mean BOD_5 shown in Table 14 for stream H is 17.1 mg/l and for stream J is 167 mg/l.

The amounts of wastes carried by the streams varied erratically with time and were poorly related with flow rates and temperature. The wastes washed directly from the milking parlors overshadowed the wastes reaching the streams from the surrounding pastures. However, the streams were generally more polluted during the summer than during the winter and pollution increased with surface runoff.

Poultry Waste Study

Hydrological Data

The correlations of T_x and T_n with the pollution indices were usually low at the poultry waste sites although some significant correlation coefficients were obtained at site P where large temperature variations occurred during the study period covered. Even at site P, however, the correlations were too inconsistent to suggest a relationship between temperature and the quality of the stream water.

Table 14. Summary of surface water pollution from the dairy sites.

Variable		Site H			Site J			Fresh Wastes
		max	mean	min	max	mean	min	
Area, ac			70			15		
Cows			75			155		
q	cfs		.063			.053		
	10^6 ft^3/yr		1.99			1.67		
	gal/day/ac		580			2280		
	gal/day/cow		543			222		
FC	col/100 ml	78×10^6	2.3×10^6	1	215×10^6	8.6×10^6	28×10^3	
	10^6 col/day/ac		51,100			725,000		
	10^6 col/day/cow		47,200			72,300		5400[a]
COD	mg/l	1525	139	2.0	2930	504	32.5	
	lb/day/ac		.675			9.58		
	lb/day/cow		.630			.935		5.78[b]
BOD_5	mg/l	350	17.1	.1	1430	167	10.0	
	lb/day/ac		.083			3.08		
	lb/day/cow		.078			.308		1.32[b]
TOC	mg/l	520	28.0	3.0	1790	182	24.0	
	lb/day/ac		.136			3.36		
	lb/day/cow		.127			.337		
BOD_5/COD			.18			.28		
BOD_5/TOC			.59			.73		
TOC/COD			.33			.32		

Table 14. (Continued)

Variable		Site H max	Site H mean	Site H min	Site J max	Site J mean	Site J min	Fresh Wastes
TN	mg/l	40.0	7.1	.7	90.8	18.6	1.5	
	lb/day/ac		.0345			.3540		
	lb/day/cow		.0322			.0335		.37[b]
TN/NH_3-N			1.41			3.37		
NO_3-N	mg/l	5.85	.75	.05	10.0	2.19	.02	
	lb/day/ac		.0036			.0417		
	lb/day/cow		.0034			.0041		
PO_4	mg/l	30.5	4.6	.5	62.0	18.3	.3	
	lb/day/ac		.0224			.3485		
	lb/day/cow		.0208			.0339		

[a] Gieldrich (1966).

[b] Witzel et al. (1966).

The rates of flow, q_t, q_b and q_o, were poor measures of the degree of pollution from sites P and X. The base flow at site X was constant at zero since the station was located in a meadow strip and thus no correlation could be expected between q_b and the pollution indices for the site. The negative correlation coefficients for q_t and q_o with the pollution indices obtained for data group X2, the data group for the runoff period shortly after the poultry wastes were spread, indicates that the runoff was more polluted at low rates of flow. Higher flow rates resulted in lower concentrations of wastes although the amount of wastes which reached the station was greater on a unit time basis.

The flow data presented in Table 15 for site P were obtained by using the average base flow rate in the stream at the time of sampling as the average water yield from the watershed. The flow rate represents a yield of 7.4 in/ac/yr. The flow rate at site X averaged 0.006 cfs during the period of study. This value was used to obtain the results in Table 15 for site X and represents a yield of 10.4 in/ac/yr.

Pollution Indices

The data in Table 15 pertaining to the number of hens contributing wastes at the two sites were selected on the following basis: Site P received wastes from a total of 10,500 hens per year in three equal applications. Since the wastes were spread on regular intervals of about four months, the number of hens was taken as 10,500. At site X only one application of wastes was made. The wastes were equivalent to the yearly wastes from about 3200 hens. The number of hens contributing wastes was taken as 9600 by assuming that a total of three such additions of wastes could be made per year with similar results of runoff amount and quality.

The pollution indices were often significantly correlated with one another. Exceptions were normally associated with low index values which suggests the tests were too inaccurate to point up the correlation on the less-polluted samples.

In view of the amount of natural pollution measured in stream F, the control stream for the swine waste study, the pollution observed in stream P was most likely from natural sources. No change in the quality of the stream was discernible following the two periods of waste spreading as compared to the quality before spreading. The pollution indices followed the same trends observed in stream F of increasing surface runoff. Also, FC counts increased with warmer temperatures.

The pollution indices at site X before the poultry wastes were spread were quite high. All index values increased after waste spreading, reflecting considerable poultry wastes in the runoff. For example, the average BOD_5 increased from 9.8 mg/l to 370 mg/l. Pollution indices for runoff two months after the wastes had been spread showed that some poultry wastes were still being removed from the field. For example, the average BOD_5 was 22.5.

Results of calculations of the amount of pollution carried by the poultry streams are shown in Table 15. The value of FC/day/hen at site P

Table 15. Summary of surface water pollution from the poultry sites.

Variable		SITE P max.	P mean	P min	SITE X max.	X mean	X min
Area, ac			65			5	
Hens			10500			9600	
q	cfs		.055			.006	
	10^6 ft^3/yr		1.73			.19	
	gal/day/ac		547			777	
	gal/day/hen		3.4			.4	
FC	col/100 ml	160000	9600	1	1050	235	50
	10^6 col/day/ac		190			6.9	
	col/day/hen		1.2×10^6			3600	
COD	mg/l	535	63.2	1	1720	600	33
	lb/day/ac		.285			3.90	
	lb/day/hen		0.0014			.0020	
BOD_5	mg/l	22	5.2	.1	1070	264	7.5
	lb/day/ac		.023			1.66	
	lb/day/hen		0.0001			.0009	
TOC	mg/l	41	14.2	4.0	1108	322	28
	lb/day/ac		.063			2.02	
	lb/day/hen		0.0004			.0011	
BOD_5/COD			.086			.422	
BOD_5/TOC			.298			.844	
TOC/COD			.313			.507	
TN	mg/l	24.6	1.9	.3	270	60	.1
	lb/day/ac		.009			.390	
	lb/day/hen		0.00005			.0002	
TN/NH_3-N			3.17			---	
NO_3-N	mg/l	9.00	1.55	.01	4.85	2.00	.05
	lb/day/ac		.007			.013	
	lb/day/hen		0.00004			0	
PO_4	mg/l	7.9	1.2	.1		---	
	lb/day/ac		.005			---	
	lb/day/hen		0.00003			---	

was obtained by multiplying the mean of all FC measurements made on the samples from stream P by $\overline{q}$ for stream P. The value for BOD_5/COD at site P was obtained from all paired BOD_5 and COD measurements made on the samples from stream P. The other results were obtained in a similar manner.

Although the results in Table 15 include contributions from natural sources, the amounts of pollution per day per hen are less than 1/10 of the average production rates from fresh poultry wastes. For example, the BOD_5 carried by stream P, 0.00014 lb/day/hen, accounted for only 0.6 percent of the BOD_5 production by the hens based on an average production rate of 0.024 lb/day/hen.

Discussion

The data obtained from study of the two poultry waste disposal sites suggest that land spreading can be effective in controlling stream pollution. However, the application of wastes at high rates on bare soil and in drainage ways, as was the case at site X, results in considerable water pollution. This points to the need for criteria to guide the selection and management of disposal areas. However, even in cases where the site of disposal is poorly located, the amount of pollution which reaches the stream is a very small proportion of the potential pollution from poultry wastes.

Beef Waste Study

Hydrological Data

The correlations of T_x and T_n with the pollution indices were low almost without exception at the beef pasture site although sufficient variations occurred in the temperature to point-up relationships if they had existed. Correlations between flow rates and the pollution indices were also poor. Nutrient contents in the stream were low and may have accounted for the lack of correlation. FC counts were higher during warmer weather. This dependence probably caused the lack of correlation between FC and flow rates.

The flow data presented in Table 16 were obtained by averaging the flow rates in stream Z for the period of study. In this case the average base flow rate at the times of sampling, 0.007 cfs, was not a good estimate of the average flow rate in contrast to what was true at the other study sites. This difference was due to a lack of increase in base flow at site Z when rainfall-runoff events occurred and was probably associated with the geology of the watershed.

Pollution Indices

The pollution indices at site Z were often significantly correlated with each other except when the values of the indices were low. As was the case with the other land disposal sites, BOD_5 and TOC showed the best correlations with the other indices.

Table 16. Summary of surface water pollution from the beef site.

Variable		Max	Mean	Min
Area, ac			25	
Cows			35	
$\bar{q}$	cfs		.020	
	$10^6 ft^3/yr$		.63	
	gal/day/ac		517	
	gal/day/cow		370	
$\bar{\bar{FC}}$	col/100 ml	460,000	30,700	1
	10^6 col/day/ac		580	
	10^6 col/day/cow		430	
$\bar{\bar{\bar{COD}}}$	mg/l	695	149	8.0
	lb/day/ac		.645	
	lb/day/cow		.460	
$\bar{\bar{\bar{\bar{BOD_5}}}}$	mg/l	50	9.8	.3
	lb/day/ac		.041	
	lb/day/cow		.0303	
$\bar{\bar{\bar{TOC}}}$	mg/l	206	32.5	6
	lb/day/ac		.136	
	lb/day/cow		.1000	
BOD_5/COD			.080	
BOD_5/TOC			.330	
TOC/COD			.278	
TN	mg/l	3.1	1.2	.3
	lb/day/ac		.0052	
	lb/day/cow		.0037	
TN/NH_3-N			6.0	
NO_3-N	mg/l	3.20	1.35	.01
	lb/day/ac		.0058	
	lb/day/cow		.0042	
$\bar{\bar{\bar{PO_4}}}$	mg/l	1.9	1.1	.4
	lb/day/ac		.0048	
	lb/day/cow		.0034	

Results of calculations of the amounts of pollution carried by stream Z are shown in Table 16. The value of FC/day/cow was obtained by multiplying the mean of all FC measurements made on the samples by the average flow rate. The value for BOD_5/COD was obtained from all paired BOD_5 and COD measurements. The other results were obtained in a similar manner. By using the same values for fresh waste production as were used for the diary cows, the FC was 8 percent, the BOD_5 2 percent, the COD 8 percent, the PO_4 2 percent, and the N (TN plus NO_3-N) 2 percent of the average production rates for fresh wastes.

Discussion

The stream draining the beef pasture site was more polluted than would be expected from natural sources indicating that some wastes from the animals did reach the stream. However, the amounts of pollution atrributable to the beef animals was extremely low compared to the wastes produced. Most of the pollution which could be attributed to the animals was likely associated with wastes voided in the stream and the drainage paths leading to the stream.

SUMMARY

The purpose of this study was to investigate the actual and potential importance of animal wastes in agricultural land runoff with respect to water quality management in the Southeast. It included:

1. the measurement of rainfall, runoff, bacterial densities, organic materials and nutrients carried to streams from swine, dairy, poultry, and beef growing areas;

2. the development of data and relationships for estimating the effects of animal waste disposal under similar conditions at other locations;

3. the assessment of present animal waste disposal practices;

4. recommendations for corrective action; and

5. identification of researchable problem areas.

Twelve sites were studied. These included six swine, two dairy, two poultry, one beef, and one control watershed. Waste disposal practices at each of the sites were as follows:

Swine		
	Anaerobic lagoons	3 sites
	Land spreading	2 sites
	Direct discharge	1 site
Dairy		
	Partial separation of solids with land spreading and direct discharge of remaining wastes	2 sites
Poultry		
	Land spreading	2 sites
Beef		
	Land spreading (grazing)	1 site
Control watershed		1 site

Sites are typical of present animal growing and waste handling practices in the Piedmont Region of North Carolina.

Data were collected from each production site to ascertain the amount and strength of wastes produced and eventually discharged to receiving streams under varying conditions of rainfall, runoff, and temperature. Time of flow-through measurements were made for the lagoons. Attempts to determine the time of flow from land-runoff areas used for waste disposal were unsuccessful.

More than 1500 samples were collected in iced containers by automatic samplers developed for the study. Analytical techniques commonly used to determine the quality of waters and waste-waters were not all directly applicable to the characterization of animal wastes, waste lagoon effluents, and highly polluted stream samples. Interferences were attributed to solids, dilution requirements, and toxic substances common to these wastes. The biochemical oxygen demand varied directly with dilution at BOD_5 levels exceeding 60 mg/l. While unsatisfactory for raw wastes and lagoon effluents, BOD was generally applicable to stream samples. Difficulties encountered in automated nutrient analyses due to high solids content were corrected by modifying the analytical techniques. Sample preservation and storage for subsequent nutrient analyses using freezing proved satisfactory but not ideal.

The total organic carbon analysis was applicable to all samples and provided a convenient, rapid, and dependable method for determining the organic strength of wastes and waste waters sampled during the study. Good correlations existed between BOD_5 and TOC for the land runoff samples but not the concentrated wastes. Difficulties common to the standard BOD analysis for water containing high concentrations of animal wastes (lagoon liquor and raw wastes) and the variability of BOD/TOC with the degree of treatment precluded development of a general BOD/TOC relationship for those wastes. Nevertheless, conjunctive use of BOD and TOC parameters was useful in characterizing all samples and was particularly useful when toxic materials and/or other factors limited the applicability of the BOD test. The degree of BOD/TOC variability was one indication of waste consistency and the possible presence of toxic materials. The BOD/TOC ratio also provided an indication of the ease of biodegradation and/or the degree of stabilization.

Fecal streptococci were lower than expected. The lower counts were likely due to the KF medium used. The applicability of the medium to waters containing animal wastes was not checked.

The simple regression analyses revealed relatively high correlations between many of the pollution indices which can be usefully developed as a tool in water quality management. Certain of these are summarized from Table 17.

Table 17. Correlation of TOC with other pollution indices for land-runoff studies

Site	r			
	FC	BOD_5	TN	TP
E (swine)	0.437	0.966	0.875	0.899
H (dairy)	0.838	0.970	0.708	0.714
PX (poultry)	0.491	0.610	0.926	0.730
Z (beef)	0.895	0.724	0.955	0.620
Control	0.406	0.734	0.943	0.883

The following simple regression equations with TOC as the independent variable and BOD_5 as the dependent variable demonstrate the types of potentially useful relationships which can be developed for the assessment of pollution under applicable conditions:

Land runoff from

	Site
Swine wastes	E
$BOD_5 = 0.79\ TOC - 2.5$	
Dairy wastes	H
$BOD_5 = 0.66\ TOC - 2.0$	
Poultry wastes	P & X
$BOD_5 = 0.35\ TOC$	

TOC is particularly promising for this purpose because the analysis is simple, rapid and reliable.

Multiple regression analyses using atmospheric temperature, streamflow, and number of animals as independent variables and the principal pollution indices (FC, TC, BOD_5, TOC, TN, NH_3, NO_3, TP, and OP) as dependent variables did not produce estimating equations of general applicability. Inconsistencies between data groups with high coefficients of multiple determination were experienced. These are attributed to vegetative cover, antecedent moisture, topography and soil types, time of waste application with respect to rainfall, distance of disposal site from stream, duration and intensity of rainfall, and possibly other factors. However, high R^2 values for some of the land runoff data groups show promise that equations of general applicability for predicting stream pollution from land runoff sites can be developed. Estimating equations for BOD_5 and TOC from the control watershed are examples. Normative values for these indices range between 1-2 and 5-10 mg/l, respectively, in the absence of runoff. The regression equation from data group F23 with an r^2 of 0.604

$$BOD_5 = 2.8 - (0.035)(T_n) + 2.2\ (q_o)$$

produces an estimate of less than 1 mg/l at 80°F and a flow of 0.10 cfs. The TOC regression equation for the same data group has ($r^2 = 0.498$)

$$TOC = 5.6 + (0.024)(T_n) + (13.9)(q_o)$$

estimates a TOC of 9 mg/l under the same conditions. The range in flow experienced during the study was 0.025 - 2.1 cfs. These values are consistent with typical base-flow conditions for land runoff study sites.

Very little information is available on the quality of water from natural watersheds. The following data from control watershed F indicates that this can be appreciable under conditions of rainfall and land runoff and needs to be taken into consideration in water quality management.

Table 18. Average amounts of stream pollution from control watershed

	FC col/100 ml	BOD mg/l	TOC mg/l	TN mg/l	PO_4 mg/l
Maximum	800,000	16.8	380	15.6	4.0
Mean	10,000	2.0	14.6	1.2	0.2
Minimum	1	0.1	3.0	0.1	0.1

The normative amounts of wastes reaching receiving streams from typical animal-growing operations are summarized in Table 19.

Table 19. Average amounts of wastes in land runoff from representative animal-growing operations

	FC	BOD_5	TOC	N	PO_4
	10^6 col/day /animal	lb/day/animal			
Swine					
Direct discharge[1]	30,000	0.176	0.128	0.032	0.017
Anaerobic lagoons[2]	910	0.154	0.156	0.009	0.005
Land spreading[3]	630	0.003	0.007	0.002	0.001
Dairy[1]	60,000	0.190	0.230	0.034	0.027
Beef[3]	430	0.030	0.100	0.008	0.003
Poultry[3]	0.6	0.0005	0.0007	0.0002	0.00003

[1] Sampling station downstream from point of discharge with intervening section of stream providing some stabilization and settling.

[2] Lagoon effluent.

[3] Sampling station at base of watershed immediately below site.

These data vividly illustrate the importance of animal wastes as a source of pollution. Wastes from a herd of 1000 swine following treatment by anaerobic lagoon is roughly equivalent to the raw sewage from a community of 1000 population. Land spreading as a means of disposal reduces the BOD_5 of the raw waste by at least 99 percent as compared to about 50 percent for the lagoons. The present practice of dairy waste disposal produces considerably more pollution on a per-animal basis and is also unsatisfactory. Pollution from beef pasture, while only 15 percent of the discharge from dairies is unexpectedly high. Animal access to stream is an important causative factor. Poultry waste disposal by land spreading was found to be entirely satisfactory in one case and a major source of pollution in the other because of unsatisfactory spreading practice.

Conclusions and recommendations are presented on pages 2-5 of this report.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contribution of the following persons to this project:

Mr. Lloyd P. Tyler, Director, N.C. Department of Water and Air Resources Laboratory; Mr. Darwin Coburn, Director, Division of Water Pollution Control; and Mr. Earle C. Hubbard, Assistant Director, Department of Water and Air Resources, for services and consultation associated with nutrient analyses using the Department's auto-analyzer.

Mr. James F. Koon, Mr. Amos F. Biles, and numerous part-time employees for their dedicated field work and laboratory analyses.

Dr. Robert S. Sowell, Dr. Sun-fu Shih, and Dr. Larry A. Nelson for assistance with the data analyses.

Dr. Frank J. Humenik for consultation and advice on technical problems.

Mr. Harold Snyder and Mr. Donald Anderson of EPA for their assistance in the direction of the grant and the preparation of this manuscript.

Dr. Jackie W. D. Robbins, Research Associate
Dr. David H. Howells, Project Director
Dr. George J. Kriz, Associate Department Head

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APPENDIX

Appendix A

Automatic Sampler

An automatic sampler developed to collect the effluent samples for the study is presented in Figures 30, 31, and 32 (Robbins and Kriz, 1970). Advantages of the sampler include D.C. operation, reliability, simplicity, and economical construction. Features to satisfy specific requirements of sampling are easily incorporated into the basic design. Samples collected with the automatic sampler showed no significant difference from grab samples in content of nutrients (Kjeldahl, ammonia, nitrate and nitrite nitrogen, and total and orthophosphate), "organics" (biochemical oxygen demand, chemical oxygen demand, total organic carbon, total solids and volatile solids), bacteria (total coliform, fecal coliform and fecal streptococci), pH, or specific conductivity.

The sampler has the capability to collect and store water samples from intermittently or continuously flowing streams. Up to twenty-four individual quart samples can be collected on a variable time basis. Each narrow mouth mason jar is fitted with an #11 1/2 rubber stopper that has a 1/16-inch air vent and a 1/4-inch sample inlet. The inlet is fitted into a 1/4-inch diameter teflon or polyethylene tubing through which the sample enters the jar. The jars are stored on an expanded metal tray inside an insulated box that is made of 2-inch styrofoam covered with sheet metal. The container keeps ice for several days.

When the water level in a stream raises the float (31-1)[1] sufficiently to close the microswitch (31-2), the sampling sequence begins. The sampling time interval is preset by choosing the desired combination of time of revolution of the chart drive (31-3) and number of notches on the chart drive drum. When the chart drive closes the microswitch (31-4), the pump (31-5) and solenoid (31-6, 32-6) are activated. The solenoid (31-6, 32-6) orients the terminal end of the 5/8-inch pump tube to one of the sample inlet tubes by rotating the pull wheel (32-7, 33-7) 1/12 of a revolution. This moves the pump tubing holder (32-8, 33-8) one inch horizontally. The time delay relay (31-9) breaks the electrical circuit after sufficient time is allowed to collect the sample. This prevents the battery from discharging needlessly and the solenoid from overheating. Then, the plunger return spring (32-10) moves the solenoid plunger to the next notch on the pull wheel (32-7, 33-7). As the chart drive (31-3) continues to revolve, the microswitch (31-4) opens. This allows the time delay relay (31-9) to close and the sequence for taking the next sample begins when the microswitch (31-4) is again closed by the chart drive. When the water level drops sufficiently to close the microswitch (31-2), the sampling sequence stops.

The friction spring (33-11) regulates the pull necessary to rotate the pull wheel (32-7, 33-7) and to prevent the wheel from rotating backwards when the solenoid plunger is pulled by the plunger return spring (32-10). The chart drive (31-3) may also be used to record the water level in the stream.

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[1] Two numbers in parenthesis refer to specific Figure-Component.

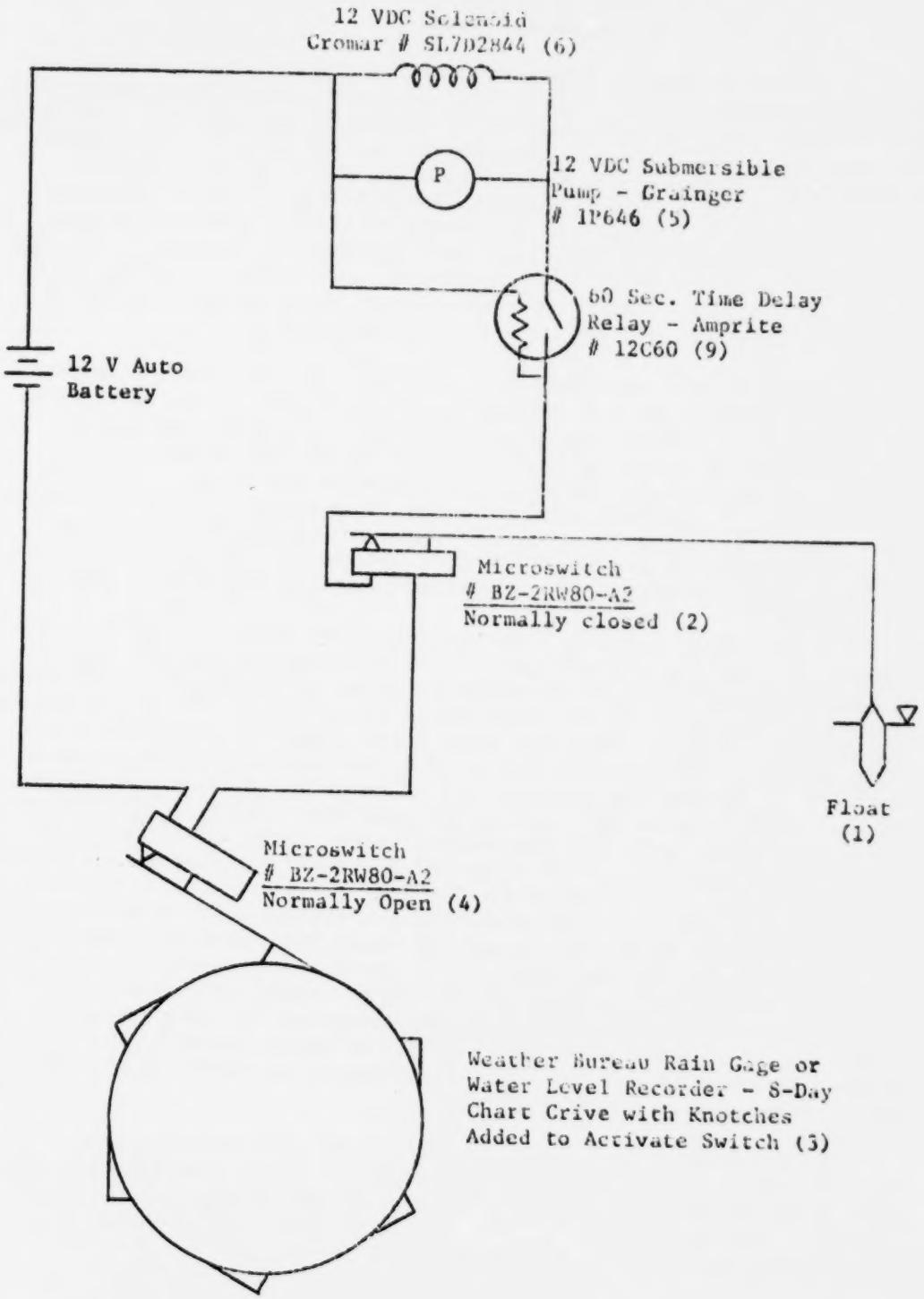

Figure 30. Circuitry for automatic sampler

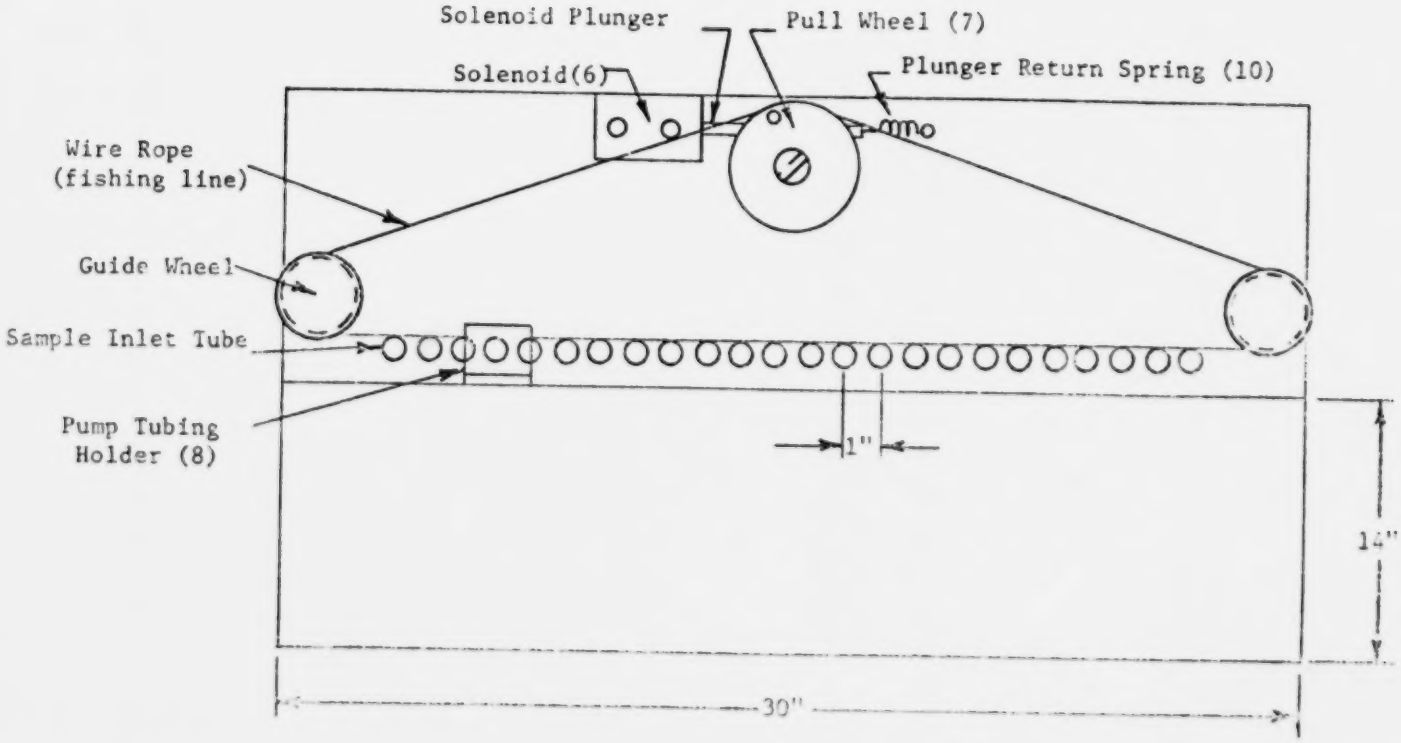

Figure 31. Advancing mechanism for automatic sampler

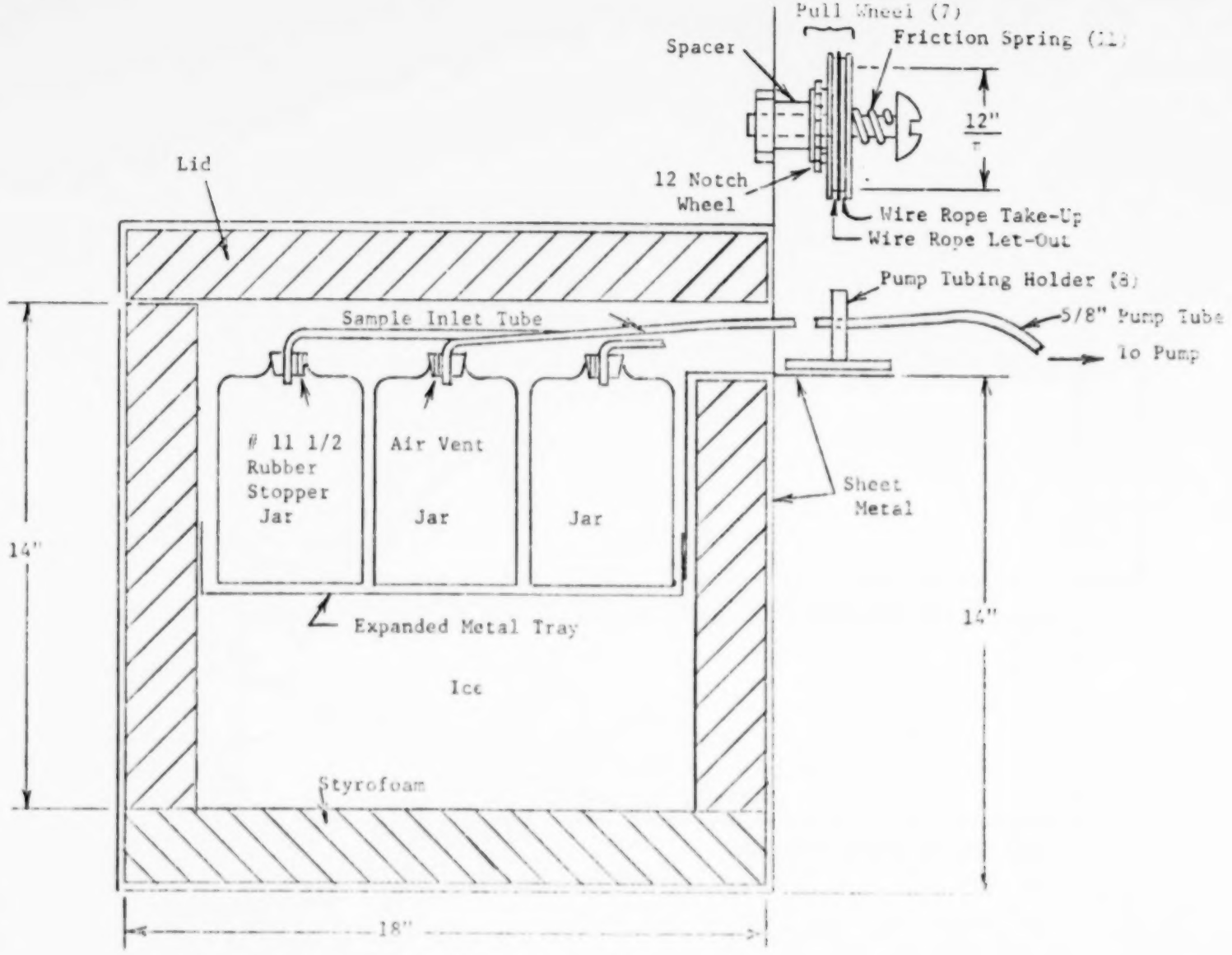

Figure 32. Cut-away view of automatic sampler

Cost of materials excluding the chart drive is less than one hundred dollars and the labor required for construction does not exceed two man days. Useful modifications include use of an additional solenoid for added pull (connected in parallel electrically), separate circuits for the pump and solenoid, and different size sample containers.

Appendix B

Illustrative pages from the Supplemental Appendix reporting the following:

Raw data

Simple statistics by data groups

Regression coefficients

Illustrative Page - raw data

Poultry Study Data

The key to the listing in Table 25 is the same as for Table 23 except for changes as follows:

Column	Data	Units
20-27	COD	10^{-1} mg/l
53-56	Blank	-
61-63	Blank	-

Table 25. Listing of effluent quality and hydrological data by data groups, poultry study

m	d	h	d_t	d_b	FC	COD	BOD_5	TOC	TN	NH_3	NO_3	TP	T_x	T_n
DATA GROUP X1														
2	2	14	1	C	100	520	120	370		1	5			5829
2	3	9	2	C	174	330	75	280		1325				6648
DATA GROUP X2														
216	5	40	C			12400	10700	10680						
21610		46	C			9080	1000	10620		2700	6			6346
21611		52	C		100	11250	8200	11080		2400	45			6346
21612		50	C		80	14800	3800	6780		1930	45			6346
21613		49	C			14250	6500	6640		1330	155			6346
21615		48	C		100	9250	4800	4180		1350	30			6346
21616		47	C		1050	17200	5200	5600		850	126			6346
21618		60	C			6740	3060	2950		1210	30			6346
21620		72	C			5400	1300	2080		670	48			6346
21622		90	C			5770	1400	2430		350	123			6346
21624		78	C			4930	1080	2060		260	151			6346
217	2	70	C		510	3410	700	1100		200	160			6346
217	4	64	C			3220	620	1000		180	227			4832
217	6	53	C			2730	620	810		150	238			4832
217	8	46	C			2790	740	860		180	368			4832
21710		42	C		200	2540	680	850		250	370			4832
21712		37	C			2760		860		220	350			4832
21716		25	C			4620		950		300	313			4832
21718		18	C		170	4530		1020		240	350			4832
DATA GROUP X3														
331	4	31	C		290	5200	190	390		320	295			4832
331	8	10	C		180	2320	360	450		12160				3834
4	116	16	C		230	4950	250			10250				3834
4	118	12	C		50	2470	156			12130				6237
4	2	7	6	C						7235				6237
4	2	9	15	C	60	2390	170			9375				6848
										7485				6848

Illustrative Page - raw data

Table 96. Conductivity, pH, COD, TS, VS and FS data by site and date

Site	Time			Conductivity, ohms	pH	COD	TS	VS	FS, col/100 ml
	mo	day	hr				mg/l		
A	10	13	21				2570	1460	
A	10	13	22				2540	1460	
A	10	14	3		7.1		2570	1450	
A	10	14	6				2570	1460	
A	10	14	8		7.4		2330	1180	
A	10	14	9				2280	1130	
A	10	13	18				2370	1316	
A	10	19	12		7.3		2560	1620	
A	10	19	16				2300	1310	
A	10	19	20				2170	1410	
A	10	19	24				2110	1470	
A	10	20	4				2060	1310	
A	10	20	8				2190	1530	
A	10	20	12				2160	1510	
A	10	20	18				2090	1400	
A	10	21	11				2160	1150	
A	10	21	12				2140	1150	
A	10	21	14				2150	1060	
A	10	21	16				2220	1250	
A	10	21	12				2150	1230	
A	10	22	14				2170	1070	
A	10	22	22				2180	1120	
A	10	23	12				2150	1130	
A	10	23	14				2070	1120	
A	10	30	5						110,000
A	11	5	12						100,000
A	11	6	12						60,000
A	11	18	12				1980	840	
A	11	21	13				1960	970	
A	11	20	9	5.3	7.2	1230	1890	850	
A	11	22	12				1940	850	
A	11	23	9				1830	810	
A	11	22	10				1210	650	
A	11	18	20	5.2	7.4	950	1250	590	
A	11	25	10	6.0	7.3		1050	370	
A	1	22	10						82,000
A	2	27	10						1,400,000
A	2	27	12						160,000
A	2	18	20		7.4				
A	2	24	12	5.2	7.3				
A	2	24	24	6.0					
A	2	25	10	5.5			980	390	
A	3	25	16				1200	600	
A	4	29	9	46.1	7.9	1100			

Illustrative Page

Table 27. Simple statistics for FC paired with other data by data groups

GROUP	M / s / r x 10^3 / No.													
	TC	BOD_5	TOC	TN	NH_3-N	NO_3-N	TP-PO_4	OP-PO_4	T_x	T_n	H	q_t	q_b	q_o
	col/100 ml	mg/l							°F			cfs		
ABC	1262640	378	366	222	173		126	109	59	38	206	.015	.003	.012
	920434	136	97	65	75		251	239	13	13	102	.026	.006	.025
	684*	-442*	037	-430*	-489*		-186*	035	-247*	-181*	-202*	-050	-034	-042
	197	198	135	178	104		189	103	206	206	206	206	206	206
A	1254095	384	396	243	187		140	118	65	43	300	.027	.005	.022
	678675	88	67	44	41		17	21	12	13	000	.030	.008	.031
	521*	096	-023	156	242		-036	-006	-025	.171	000	215**	130	177
	105	105	54	100	59		105	70	111	111	111	111	111	111
A1	1328764	393	436	255	203		144	124	65	43	300	.027	.002	.025
	663534	67	22	33	28		14	18	11	13	000	.033	.002	.033
	485*	-175*	-222	119	284**		082	087	330*	480*	000	283*	303*	266*
	89	86	35	85	45		89	57	90	90	90	90	90	90
A11	1648545	371		279	223		153	128	71	50	300	.019	.003	.016
	556794	65		19	18		9	18	7	10	000	.030	.002	.029
	472*	-146		-452*	024		-454*	-009	167	418*	000	585*	199	584*
	55	51	0	51	26		55	43	55	55	55	55	55	55
A12	811471	424	436	219	175		131	113	56	32	300	.040	.001	.039
	469714	59	22	8	10		11	10	11	10	000	.032	000	.032
	192	133	-222	-337*	178		101	261	218	324	000	146	000	146
	34	35	34	34	19		34	14	35	35	35	35	35	35
A2	838750	347	323	176	138		119	92	63	44	300	028	.020	009
	627247	149	62	33	386		14	9	16	15	000	014	.010	.012
	829*	395	178	527**	535**		-476	-321	-700*	-524*	000	002**	507**	-391
	16	19	19	15	14		16	13	21	21	21	21	21	21

Illustrative Page

Table 81. Regression equation coefficients for FC = $f(T_n, H, q_o)$, col/100 ml, by data groups

Group	1	T_n, °F	H	q_o, cfs	R^2	No.
ABC	814753.2	-3989.7		980020.8	.055	205
A	236361.5	7351.6		-735129.4	.068	111
A11	404942.4	253.5		3746235.4	.341	55
A12	584939.3	-871.9		-2754365.2	.061	35
A2	-182311.0	28834.1		-28077396.9	.404	21
A23	-621116.5	41709.5		17659091.7	.486	8
A24	3141196.3	-64120.9		18660264.9	.535	5
A25	-55930.1	30784.4		-35972368.7	.810	8
B	1798357.6	-21057.8		-71725211.0	.192	49
B1	2034901.0	-27922.0		251603898.9	.333	34
B2	-1982044.9	106866.1		-550226847.6	.376	13
B22	-5705196.7	227615.4		-1060629750.3	.798	8
B23	-2462572.5	151768.5		-914833474.8	.658	5
C	2649107.8	-8821.4		-105681555.7	.005	48
C1	2286429.6	8027.0			.001	35
C2	-768689.3	47421.6		24275708.9	.119	8
C22	4144672.2	-110631.2		57037555.8	.141	6
D	1585895.2	-81329.6	24707.0	-24737.3	.052	88
D1	-364441.4	-6110.3	6395.6	-3263489	.575	8
D2	11190679.0	-193961.5		1936064.2	.201	25
D3	982076.4	1220.7		-205677.6	.004	26
D4	111349657.3	-1571491.7		174500.9	.133	29

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
W	05B	

5 Organization

Department of Biological and Agricultural Engineering
School of Agriculture and Life Sciences
North Carolina State University at Raleigh

6 Title

Role of Animal Wastes in Agricultural Land Runoff

10 Author(s)

Robbins, Jackie W. D.
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Kriz, George J.

16 Project Designation

EPA/ORM Grant No. 13020 DGX 08/71

21 Note

22 Citation

23 Descriptors (Starred First)

*Animal Wastes, *Farm Wastes, *Runoff, *Agricultural Wastes, *Water Pollution, *Farm Lagoons

25 Identifiers (Starred First)

*Animal Wastes, *Agricultural Land Runoff

27 Abstract

Twelve typical agricultural areas representing three types of animal waste management techniques--lagooning, direct discharge into streams and land spreading including pasture and drylot units--were studied to determine the amounts of and factors governing stream pollution from swine, dairy, beef, and poultry production operations.

More than 1500 stream and lagoon effluent samples were collected with an automatic sampler developed for the study. The samples were analyzed for bacteria, nutrients, and degradable organics. Hydrological and waste management data were also collected.

Study results point to the superiority of land spreading for the disposal of animal wastes. Good soil and water conservation practices should be used to minimize the movement of wastes into streams. Higher rates of runoff result in heavier pollution. The location of disposal areas away from streams is important in controlling the amount of entering wastes. Even when land disposal areas are poorly located, the amount of pollution entering streams is usually low; and watershed factors, such as surface culture and ease of erosion, are of primary importance in governing the magnitude of pollution which reaches the streams. Direct dumping of animal wastes, treated or untreated, into streams is completely unacceptable and should be prohibited.

Abstractor David H. Howells

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WR:102 (REV. JULY 1969)
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